# Data Product and Archive Volume Software Interface Specifications

# EPOXI

# Raw and Calibrated Science Data Products for

# Hi-Res IR Spectrometer (HRII)
# Hi-Res Visible CCD (HRIV)
# Medium-Res Visible CCD (MRI)

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## Modification History

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| 2009-01-02 | S. McLaughlin | Fix typos; Add missing keyword definitions. |

# Table of Contents

# 1 Introduction

## 1.1 Purpose and Scope

The purpose and scope of this document is to describe the Level 2 (raw) and Level 3/4 (calibrated) science data products for the three EPOXI instruments as well as the format and content of the PDS archival data sets. The processing levels are defined in Appendix 7.3. This document is intended to provide enough information to enable users to understand and use the data products, and it includes examples of the science data products and information about how the data were processed, formatted, and labeled.

This document is not intended to provide a detailed description of the EPOXI instruments nor does it provide methods for interpreting the scientific data. A thorough discussion of the EPOXI instruments is provided by Hampton, et al. 2005 [4]. The Deep Impact Instrument Calibration paper by Klaasen, et al. 2008 [7] describes an existing calibration pipeline that is the basis for EPOXI. For overviews of the Deep Impact flyby spacecraft and the autonomous navigation system, see A'Hearn, et al. 2005 [5], Blume, 2005 [6], and Mastrodemos, et al. 2005 [8].

## 1.2 Applicable Documents

### 1.2.1 External Standard References

[1] PDS Standards Reference, JPL, D-7669, Version 3.7, March 20, 2006

[2] PDS Data Dictionary, JPL, D-7116, Revision E, August 28, 2002 and the EPOXI Local Data Dictionary created from the PDS Full Data Dictionary generated on January 24, 2008.

### 1.2.2 Project Documents

The following project-related publications are included in the documentation for the PDS archive.

[3] EPOXI Data Management and Archiving Plan, JPL, D-39796

[4] An Overview of the Instrument Suite for the Deep Impact Mission, Hampton et al, Space Science Reviews, 2005

[5] Deep Impact: A Large-Scale Active Experiment on a Cometary Nucleus, A'Hearn, et al. Space Science Reviews, 2005

[6] Deep Impact Mission Design, Blume, Space Science Reviews, 2005

[7] Deep Impact Instrument Calibration, Klaasen, et al., Review of Scientific Instruments, American Institute of Physics, 79, 091301, 2008, DOI: 10.1063/1.2972112

[8] Autonomous Navigation for the Deep Impact Mission Encounter with Comet Tempel 1, Mastrodemos, et al. Space Science Reviews, 2005

[9] Deep Impact - Navigation Images Report, Carcich, 2006

[10] Deep Impact Spacecraft Clock Correlation, Carcich, 2006

[11] Deep Impact and EPOXI Instrument Thermal Sensor Atlas, Hampton, 2008

### 1.2.3 Scientific References

Scientific references, including those from Deep Impact, relevant to EPOXI are listed here.

[A] Deep Impact: Excavating Comet Tempel 1, A'Hearn, et al. 2005, Science, 310, 258-264

[B] The Extrasolar Planets Encyclopedia, http://exoplanet.eu, J. Schneider, CNRS/LUTH Paris Observatory

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# 2 Instrument Overview

An overview of the three instruments is provided here. The user of the EPOXI data archive is strongly encouraged to read project documents [4] and [7, section II] for thorough discussions of the instruments.

## 2.1 IR Spectrometer (HRII)

The High Resolution Imager (HRI) consists of a long-focal-length telescope followed by a dichroic beam splitter that reflects (0.3 to 1.0 microns) light through a filter wheel to a CCD for direct, optical imaging. The beam splitter transmits the near infrared (1 to 5 microns) to a 2-prism spectrometer. For convenience, we consider these as two separate instruments, HRIV and HRII, sharing the telescope since the two focal planes operate in parallel asynchronously. The HRI telescope is a classical Cassegrain design with the following parameters:

| | |
|---:|---|
| Primary aperture: | 30.0 cm diameter, round |
| Primary focal ratio: | 4.5 |
| Secondary Obscuration: | 9.7 cm diameter, round |
| Secondary magnification: | 7.8x (net Cassegrain focal length 1050 cm) |
| Back focal distance: | 30.0 cm |

The beam-splitter is a dichroic with equal transmission and reflection occurring at about 1.05 microns and was placed in front of telescope focal plane. The spectrometer is a 2-prism design, one of calcium fluoride (CaF_2) and one of zinc selenide (ZnSe) to maximize etendue and problems with order separation. The camera and collimator lead to a net demagnification of 3 times, for an effective f/ratio of f/12 and effective focal length of 360 cm in the final beam. The entrance slit subtends on the sky 2.53 milliradians by 10 microradians (0.145 degrees by 2 arcseconds), filling the 512-pixel height of the IR array. The slit width matchs the binned pixel (2x2) used for most observations.

The near-infrared detector is a 1024 (wavelength) x 512 (spatial) pixel mercury cadmium telluride (HgCdTe) device manufactured by Rockwell using the multiplexer originally developed under contract from the University of Hawaii for deployment in the WFC3 on HST. Physically, it is a 1024 x 1024 device, but only half of the device was active. Pixels are 18 microns square and normal operations include 2x2 binning (post-readout). Spectral resolving power, because of the 2-prism design, varies from greater than 740 at 1.04 microns down to 210 at 2.6 microns, and back up to 385 at 4.8 microns. Due to probable saturation problems in warm areas of the nucleus of the Deep Impact target, the central quarter of the detector is covered with a neutral density filter.

When operated in the 512 x 256 pixel, 2x2 binning mode, the HRII instrument has the following field-of-view characteristics:

Spatial

| | |
|---|---|
| Physical Pixel Size : | 36 micrometers |
| Effective Pixel FOV : | 10.0 microradians |
| Effective FOV : | 2.5 milliradians or 0.15 degrees |

Spectral

| | |
|---|---|
| Effective Pixel FOV : | 10.0 microradians |
| Effective FOV : | 10.0 microradians (slitwidth) |

The spectrometer includes an internal stimulator lamp for calibrating between the two quadrants of the spectrometer (i.e., not as a standard calibrator). However the lamp was broken during one of the ground thermal-vacuum tests and was not replaced. Therefore this lamp was never used during the Deep Impact and EPOXI missions.

The three instruments on the flyby spacecraft, HRII, HRIV (High- Resolution Visible CCD) and MRI (Medium-Resolution Visible CCD), are mounted on a separate instrument platform together with the star trackers. The three instruments are nominally co-aligned [7].

The HRII instrument was originally calibrated by using in-flight data acquired during Deep Impact as well as pre-launch data taken during thermal-vacuum tests (TV1, TV2, and TV4) performed in 2002 and 2003. In-flight calibrations continue through the EPOXI mission to monitor performance and to provide additional data for refining the data calibration pipeline. Instrument calibration as well as the pipeline that is shared by Deep Impact and EPOXI is discussed by Klaasen, et al. (2008) [7].

The HRII instrument generally performed as expected during flight. During Deep Impact, small changes in instrumental temperatures affected the dark current more than expected from ground thermal-vacuum tests. This effect continues for EPOXI. These thermal effects are discussed in the Deep Impact instrument calibration paper by Klaasen, et al. (2008) [KLAASENETAL2006]. Also for the prime mission in 2005, about 1.15% of the IR pixels were bad. Calibration data acquired three years later for EPOXI show this figure has increased to about 1.48%.

During the Deep Impact mission, early images of stars acquired by the HRIV CCD indicated the HRI telescope was out of focus. An analysis showed the focus was forward of the HRIV CCD, so bakeouts were performed in late February and early March 2005 to improve the focus. The bakeouts reduced the defocus from 1.0 cm to 0.6 cm, which caused the width of star images to decrease from about 12 pixels to about 9 pixels in a HRIV frame. This focus problem had only a nominal effect on the HRII instrument. For a detailed discussion about the focus of the HRI telescope, please see Klaasen, et al. (2008) [7].

### 2.1.1 Spectrometer Imaging Modes

The imaging modes for the HRII instrument are provided here.

| # | Mode Mnemonic | Mode | Stored Image Size (x, y) | Minimum Exposure Time (sec) | Frame to Frame Time for Minimum Exposure (sec) |
|---|---|---|---|---|---|
| 1 | BINFF | Binned Full Frame | 512 x 256 | 2.86 | 2.862 |
| 2 | BINSF1 | Binned Sub-Frame 1 | 512 x 128 | 1.43 | 1.432 |
| 3 | BINSF2 | Binned Sub-Frame 2 | 512 x 64 | 0.71 | 0.717 |
| 4 | UBFF | Un-binned Full Frame | 1024 x 512 | 2.86 | 2.862 |
| 5 | ALTFF | Alternating Binned Full Frame | 512 x 256 | 1.43 | 2.868 |
| 6 | DIAG | Diagnostic: One reset frame followed by a separate read frame | 1024 x 512 (each frame) | 1.43 (each frame) | 1.432 (each frame) |
| 7 | MEMCK | Memory Check | 1024 x 512 | N/A | 2.862 |

Table 1a - IR Spectrometer (HRII) Imaging Modes

For diagnostic mode 6, a reset frame is acquired first, then a read (i.e., data) frame. Each frame is stored as a separate file. Both data files use the same exposure ID with consecutive image numbers (e.g., exposure ID 1021000 and image number 001 for the reset frame and 002 for the read frame).

The IR detector has several reference columns (line samples) and rows (lines) around the edge of the array. **Pixels in the reference areas are excluded from the MINIMUM and MAXIMUM values in the PDS labels.** See Hampton, et al. 2005 [4] for more details about the instrument modes and the number of reference rows and columns for each instrument mode.

## *2.2 High- and Medium-Resolution Visible CCDs*

### 2.2.1 HRI Visible CCD (HRIV)

The High Resolution Imager (HRI) consists of a long-focal-length telescope with a dichroic beam splitter located in front of the focal plane that reflected visible light (0.3 to 1.0 microns) through a filter wheel to a CCD for direct, optical imaging. The beam splitter transmits the near-infrared light (1 to 5 microns) to a 2-prism spectrometer. For convenience, we consider these as two separate instruments, HRIV and HRII, sharing the telescope since the two focal planes operate in parallel asynchronously. The HRI telescope is a classical Cassegrain design with the following parameters:

| | |
|---|---|
| Primary aperture: | 30.0 cm diameter, round |
| Primary focal ratio: | 4.5 |
| Secondary Obscuration: | 9.7 cm diameter, round |
| Secondary magnification: | 7.8x (net Cassegrain focal length 10.5 m) |
| Back focal distance: | 30.0 cm |

The dichroic beam-splitter has equal transmission and reflection occurring at about 1.05 microns. The filter wheel contains two clear apertures and 7 filters. Five of the filters are roughly 100 nanometers in bandwidth, centered at 450, 550, 650, 750, and 850 nanometers. The shortest-wavelength filter is effectively a short-wavelength pass filter starting at 400 nanometers and limited to about 340 nanometers on the short end by the rapid decline in beamsplitter reflectivity. The longest wavelength filter is a long-pass filter starting at 900 nanometers that uses the CCD response to define the long-wavelength cutoff at about 960 nanometers.

The visible detector is a 1024 x 1024 split-frame, frame-transfer CCD with 21-micron-square pixels, with each quadrant read out through a separate amplifier. The electronics allow readout of centered sub-frames in multiples of 2: 64x64, 128x128, and so on, with or without rows of overscan. Transfer time, to move the two halves of the image from the exposing area to the two, shielded areas, is about 5.2 milliseconds. Readout time for a full frame is about 1.8 seconds.

The HRIV instrument in full-frame 1024 x 1024 mode has the following field-of-view characteristics:

| | |
|---|---|
| Pixel Size: | 21 micrometers |
| Pixel FOV: | 2.0 microradians |
| Instrument FOV: | 2.0 milliradians or 0.118 degrees |
| Surface Scale: | 1.4 meters/pixel at 700 kilometers |

The HRIV instrument includes an internal stimulator lamp for calibrating between the four quadrants of the CCD. The lamp is not a standard calibrator. One of its in-flight uses is to improve the photometry of the EPOCh exoplanet transits.

For navigation imaging [9], an HRIV observation are typically snipped into one, or more, smaller rectangular areas containing the target(s) of interest to reduce the download time. This processing is performed onboard the spacecraft, and the snips for each observation are downloaded as individual packets. The Deep Impact Science Data Center at Cornell University reconstructs the packets for each observation into the original, raw, 1008x1008 pixel image, without overclock rows and columns [7].

The three instruments on the flyby spacecraft, HRIV, HRII (High- Resolution IR Imaging Spectrometer) and MRI (Medium-Resolution Visible CCD), are mounted on a separate instrument platform together with the star trackers. The three instruments are nominally co-aligned [7].

The HRIV instrument was originally calibrated by using in-flight data acquired during Deep Impact as well as pre-launch data taken during thermal-vacuum tests (TV2 and TV4) performed in 2002 and 2003. In-flight calibrations continue through the EPOXI mission to monitor performance and to provide additional data for refining the data calibration pipeline. Instrument calibration as well as the pipeline that is shared by Deep Impact and EPOXI is discussed by Klaasen, et al. (2008) [7].

Calibration analysis combining Deep Impact and early EPOXI data determined the two halves of the HRIV CCD - the boundary being the two horizontal central lines 511 and 512 (zero based) - while physically consistent across the boundary, are biased during integration so that the centers of the two halves are apparently 1/6 pixel closer to the center, and the two boundary rows show a decrease in sensitivity of 1/6. Reconstructed image files space all lines evenly, so the true image is erroneously vertically pushed apart by 1/3 pixel at its center in these reconstructions. When making science measurements from HRIV images, one must therefore be very careful to properly account for the two flaws introduced by the apparently narrow central lines on the CCD - a geometric error that separates the image by an extra 1/3 pixel at the horizontal quadrant boundary, and 2) insertion of extra total radiance into calibrated images due to the flat-field correction, which corrects for an apparent radiance deficit in the two central rows because of the smaller number of photons actually incident on those rows.

The HRIV instrument generally performed as expected during flight for the Deep Impact and EPOXI missions. However, early in the Deep Impact mission, images of stars indicated the HRI telescope was out of focus. An analysis showed the focus was forward of the CCD, so bakeouts were performed in late February and early March 2005 to improve the focus. The bakeouts reduced the defocus from 1.0 cm to 0.6 cm, which caused the width of star images to decrease from about 12 pixels to about 9 pixels. Star images continued to have a three-fold symmetry (six points) resulting from the three-point mounting of the primary and secondary mirrors. Most of the expected resolution can be regained by applying algorithms to deconvolve the HRIV images [7]. The EPOXI mission takes advantage of the poor focus characteristic that increases the point spread function measurements, enabling high-precision photometry of known extrasolar planetary systems.

### 2.2.2 MRI Visible CCD (MRI)

The Medium Resolution Imager consists of an f/17.5 Cassegrain telescope followed by a filter wheel feeding directly onto a CCD for direct, optical imaging. The MRI telescope is a classical Cassegrain design with the following parameters:

| | |
|---|---|
| Primary aperture: | 12.0 cm diameter, round |
| Primary focal ratio: | 3.75 |
| Secondary Obscuration: | 6.6 cm diameter, round |
| Secondary magnification: | 4.75x (net Cassegrain focal length 210 cm) |
| Back focal distance: | 30.0 cm |

The filter wheel contains two clear apertures and 8 filters. The filters include duplicates of some of the medium-band filters in the High Resolution Images and filters that isolate OH, CN, and C2 as well as the green and violet continuum. These narrow-band filters are designed to match the Hale-Bopp filter sets used for ground-based programs since 1996. The longest wavelength filter is actually a long-pass filter that uses the CCD response to define the long-wavelength cutoff at about 960 nanometers.

The detector is a 1024 x 1024 split-frame, frame-transfer CCD with 21-micron-square pixels. The electronics allows readout of centered sub-frames in multiples of 2: 64x64, 128x128, and so on, with or without rows of overscan. Transfer time, to move the two halves of the image from the exposing area to the two shielded areas, is about 5.2 milliseconds. There are readout amplifiers in each of the four quadrants. Readout time for a full frame is about 1.8 seconds. Net pixel scale is 10 microradians/pixel (2 arcseconds/pixel).

The MRI instrument in full-frame 1024 x 1024 mode has the following field-of-view characteristics:

| | |
|---|---|
| Pixel Size: | 21 micrometers |
| Pixel FOV: | 10.0 microradians |
| Instrument FOV: | 10.0 milliradians or 0.587 degrees |
| Surface Scale: | 7 meters/pixel at 700 kilometers |

The MRI instrument includes an internal stimulator lamp for calibrating between the four quadrants of the CCD. The lamp is not a standard calibrator

For navigation imaging [9], an MRI observation is typically snipped into one, or more, smaller rectangular areas containing the target(s) of interest reduce the download time. This processing is performed onboard the spacecraft, and the snips for each observation are downloaded as individual packets. The Deep Impact Science Data Center at Cornell University reconstructs the packets for each observation into the original, raw, 1008x1008 pixel image, without overclock rows and columns [7].

The three instruments on the flyby spacecraft, MRI, HRII (High- Resolution IR Imaging Spectrometer) and HRIV (High-Resolution Visible CCD), are mounted on a separate instrument platform together with the star trackers. The three instruments are nominally co-aligned [7].

The MRI instrument was originally calibrated by using in-flight data acquired during Deep Impact as well as pre-launch data taken during a thermal-vacuum test (TV4) performed in 2003. In-flight calibrations continue through the EPOXI mission to monitor performance and to provide additional data for refining the data calibration pipeline. Instrument calibration as well as the pipeline that is shared by Deep Impact and EPOXI is discussed by Klaasen, et al. (2008) [7].

The MRI instrument generally performed as expected during flight. However, calibration analysis combining Deep Impact and early EPOXI data determined the two halves of the HRIV CCD - the boundary being the two horizontal central lines 511 and 512 (zero based) - while physically consistent across the boundary, are biased during integration so that the centers of the two halves are apparently 1/6 pixel closer to the center, and the two boundary rows show a decrease in sensitivity of 1/6. Reconstructed image files space all lines evenly, so the true image is erroneously vertically pushed apart by 1/3 pixel at its center in these reconstructions. When making science measurements from HRIV images, one must therefore be very careful to properly account for the two flaws introduced by the apparently narrow central lines on the CCD - a geometric error that separates the image by an extra 1/3 pixel at the horizontal quadrant boundary, and 2) insertion of extra total radiance into calibrated images due to the flat-field correction, which corrects for an apparent radiance deficit in the two central rows because of the smaller number of photons actually incident on those rows.

### 2.2.3 CCD Imaging Modes

The imaging modes for the HRIV and MRI CCD instruments are provided below. Modes where the light blocker opens and closes are identified by 'shuttered' in the Mode column. Modes where the light blocker remained open for each image are identified by 'unshuttered'.

| # | Mode Mnemonic | Mode | Stored Image Size (x & y) | # Serial Over-Clock Cols (x) | # Parallel Over-Clock Rows (y) | Minimum Commanded Exposure (sec) | Frame to Frame Time (sec) |
|---|---|---|---|---|---|---|---|
| 1 | FF | Full Frame (shuttered) | 1024 | 8 | 8 | 0 | 1.634 |
| 2 | SF1 | Sub-Frame 1 (shuttered) | 512 | 4 | 4 | 0 | 0.737 |
| 3 | SF2S | Sub-Frame 2 (shuttered) | 256 | 4 | 4 | 0 | 0.430 |
| 4 | SF2N | Sub-Frame 2 (unshuttered) | 256 | 4 | 4 | 4 | 0.232 |
| 5 | SF3S | Sub-Frame 3 (shuttered) | 128 | 2 | 2 | 0 | 0.312 |
| 6 | SF3N | Sub-Frame 4 (unshuttered) | 128 | 2 | 2 | 4 | 0.113 |
| 7 | SF4O | Sub-Frame 4 (unshuttered) | 64 | 0 | 1 | 4 | 0.062 |
| 8 | SF4NO | Sub-Frame 4 (unshuttered) | 64 | 0 | 0 | 4 | 0.062 |
| 8 | FFD | Diagnostic (shuttered) | 1024 | 8 | 8 | 0 | 1.634 |

Table 2 - Visible CCD (HRIV and MRI) Imaging Modes

The CCD arrays have several serial overclock columns (line samples) and several parallel overclock rows (lines) located around the edge of the array and the resulting images. **Pixels in the overclock areas are excluded from the MINIMUM and MAXIMUM values in the PDS labels.** See Hampton, et al. 2005 [4] for more details about the instrument modes and the overclock rows and columns.

### 2.2.4 CCD Filters

The filter characteristics for the HRIV and MRI CCD instruments are shown in Table 3. The characteristics of the filters for the HRIV and MRI instruments were:

| Filter Wheel Position | MRI Center Wavelength (nm) | MRI Filter Width (nm) | MRI Filter Target Measurement | HRI Center Wavelength (nm) | HRI Filter Width (nm) |
|---|---|---|---|---|---|
| 1 | 650 | >700[1] | Context | 650 | >700[1] |
| 2 | 514 | 11.8 | C2 in coma | 450 | 100 |
| 3 | 526 | 5.6 | Dust in coma | 550 | 100 |
| 4 | 750 | 100 | Context | 350 | 100[3] |
| 5 | 950 | 100[2] | Context | 950 | 100[2] |
| 6 | 650 | >700[1] | Context | 650 | >700[1] |
| 7 | 387 | 6.2 | CN in coma | 750 | 100 |
| 8 | 345 | 6.8 | Dust in coma | 850 | 100 |
| 9 | 309 | 6.2 | OH in coma | 650 | 100 |

[1]Filters in position 1 & 6 are uncoated fused silica and not band limited
[2]The 950 nm filter is longpass
[3]The coating on the 350 nm filter is shortpass, the substrate limits the short wavelength to ~320 nm. The dichroic beamsplitter limits the short cutoff to ~300 nm (for HRI only).

Table 3 - HRIV and MRI Filters

# 3 Archive Overview

## 3.1 Data Set and Data Volume Organization

For the EPOXI archive, the science data products are grouped into PDS data sets by target (EPOCh Exoplanets, EPOCh Earth, comet Hartley 2, or calibrations), instrument (HRII, HRIV, or MRI), and reduction level (raw or calibrated). For reference, the timeline for the EPOXI mission are provided here:

| Phase | Start Date | End Date | Targets |
|---|---|---|---|
| CRUISE | 01 Sep 2007 | 21 Jan 2008 | |
| Earth Flyby | 31 Dec 2007 | 31 Dec 2007 | Moon and calibration sources |
| In-flight Calibrations | 04 Oct 2007 | 21 Jan 2008 | Calibration sources |
| EPOCh | 22 Jan 2008 | 31 Aug 2008 | |
| Transit Observations | 22 Jan 2008 | 31 Aug 2008 | Exoplanet transit imaging |
| Earth Obs #1 | 18 Mar 2008 | 19 Mar 2008 | Earth (as a remotely-sensed planet) |
| Earth Obs #4 | 28 May 2008 | 29 May 2008 | Earth (as a remotely-sensed planet) |
| Earth Obs #5 | 04 Jun 2008 | 05 Jun 2008 | Earth (as a remotely-sensed planet) |
| In-flight Calibrations | 22 Jan 2008 | 31 Aug 2008 | Calibration sources |
| CRUISE | 01 Sep 2008 | 03 Sep 2010 | |
| Earth Flybys | Dec 2008/9 | Dec 2008/9 | Moon and calibration sources |
| In-flight Calibrations | 01 Sep 2008 | 03 Sep 2010 | Calibration sources |
| DIXI | 04 Sep 2010 | 16 Dec 2010 | |
| Hartley 2 Approach | 04 Sep 2010 | 03 Nov 2010 | 103/P Hartley 2 |
| Hartley 2 Encounter | 04 Nov 2010 | 04 Nov 2010 | 103/P Hartley 2 |
| Lookback Imaging | 04 Nov 2010 | 25 Nov 2010 | 103/P Hartley 2 |
| In-flight Calibrations | 04 Sep 2010 | 16 Dec 2010 | Calibration sources |

EPOXI science data sets are organized using the subdirectories recommended by the PDS standards:

- BROWSE
- CALIB
- CATALOG
- DATA
- DOCUMENT
- INDEX

### 3.1.1 BROWSE Directory

The BROWSE directory is optional. If present, the BROWSE directory for an EPOCh data set contains one JPEG image for each target. For DIXI encounter data sets, the BROWSE directory contains an 80x40-pixel thumbnail file and a full-size JPEG file of each image found in the DATA directory and are grouped by the observation day of year.

### 3.1.2 CALIB Directory

If present, the CALIB directory provides the files used by the pipeline to calibrate raw data for the exoplanet transit and Earth observations for EPOCh and the Hartley 2 observations for DIXI. This directory is included in the calibrated data sets. It will be included in the raw data sets if the calibration files are finalized before these data sets are generated.

The EPOXI science team produces the calibration files as a result of analyses of thermal-vacuum and in-flight calibration data from Deep Impact and in-flight calibrations acquired during EPOXI.

### 3.1.3 CATALOG Directory

This directory contains catalog files required by PDS:

- DATASET.CAT - Description of the data set
- DIF.CAT - Description of the Flyby spacecraft
- <instrument.CAT> - Description of the instrument: HRII.CAT, HRIV.CAT or MRI.CAT
- DEEP_IMPACT.CAT - Description of the mission
- PERSON.CAT - Contact information for personnel who created the data set
- REF.CAT - List of publications cited in the catalog files
- <target>.CAT - One file for each mission target, for example, HAT_P_2.CAT, XO_3.CAT, EARTH.CAT, and 103P_HARTLEY_2_1986_E2.CAT.
- CALIBRATION.CAT - Generic catalog file for all calibration targets, where the TARGET_DESC keyword in the PDS data labels provides the specific target name such as CANOPUS or DARK.

### 3.1.4 DATA Directory

This directory contains the raw or calibrated science image data grouped by level of calibration, by target, then by the year and day of year of the UTC mid-point of the observation:

<DATA>/<level><target>/<year>/<day of year>

where:

- level is RADREV for calibrated but uncleaned data in units of radiance (calibration steps can be reversed to get back to the raw DN), RAD for calibrated and irreversibly cleaned data in units of radiance, or IF for calibrated and irreversibley cleaned data in units of reflectance; level is not used in raw data sets
- target is only used for raw and calibrated EPOCh exoplanet observations data sets
- year is 4 digits
- day of year is 3 digits

### 3.1.5 DOCUMENT Directory

The DOCUMENT directory provides documentation pertaining to the raw and calibrated science data sets and nominally includes:

- Project documents listed in section 1.2.2
- Image logs when available
- A description of the quaternion found in the PDS labels
- Perpetual and leap year day-of-year calendars
- A report about the known limitations of the IR calibration pipeline and the resulting reduced data
- A report about the known horizontal, 1/3-pixel, anti-gap in the CCDs
- The IDL programs used for the calibration pipeline (provided only as documentation; the programs are not supported)
- The EPOXI local Data Dictionary which consists of the full PDS Data Dictionary plus keywords specific to EPOXI, such as EPOXI:IMAGE_MID_TIME
- The EPOXI Data Management and Archive Plan [3]
- This Software Interface Specifications Document

### 3.1.6 INDEX Directory

This directory contains a comma-separated, fixed-width, ASCII table that serves as an index into the products in the data directory. Index file includes all of the values found in the data label that are relevant to science, such as INSTRUMENT_IMAGE_MODE, INTEGRATION_DURATION, etc.

## 3.2 Expected Data Sets

### 3.2.1 In-Flight Calibrations

All raw, in-flight calibration data acquired during the various phases of the EPOXI mission will be accumulated over time and grouped into data sets by instrument for the PDS archive. In-flight calibrations include:

- Lunar observations acquired during flybys of Earth,
- HRIV darks and STIM lamp frames to aid calibration of the EPOCh observations,
- Standard EPOXI cruise calibrations for all three instruments, and
- Additional calibrations designed to further test or retest a specific instrument or observing scenario, such as instrument checkout.

| Instr. ID | Data Set ID/(Volume Set ID) | Volume Set ID | Data Products |
|---|---|---|---|
| HRII | DIF-CAL-HRII-2-EPOXI-CALIBRATIONS-V1.0 | EPXCAL_0001 | EDR: Raw, in-flight calibrations |
| HRIV | DIF-CAL-HRIV-2-EPOXI-CALIBRATIONS-V1.0 | EPXCAL_0002 | EDR: Raw, in-flight calibrations |
| MRI | DIF-CAL-MRI-2-EPOXI-CALIBRATIONS-V1.0 | EPXCAL_0003 | EDR: Raw, in-flight calibrations |

For these data sets, the TARGET_NAME in the PDS labels is always set to the value “CALIBRATION”. The actual name of the target such as “CANOPUS” or “DARK” is provided by the TARGET_DESC keyword in the labels.

If the data pipeline is modified after version 1.0 of the calibration data sets are delivered to PDS for review in early 2009, then the project will redeliver all calibration-related data as version 2.0.

### 3.2.2 EPOCh

During the EPOCh phase of the mission, the following types of data will be acquired and archived by instrument into EPOCh-specific data sets of raw data (EDR) and calibrated data (RDR - RADREV only):

- HRIV observations of eight stars with known transits by extra-solar planets, and
- HRIV, HRII, and MRI observations of Earth as an extra-solar planet.

The stars being observed for transits are:

- HAT-P 4
- HAT-P 7
- TRES-2
- TRES-3
- WASP-3
- XO-2
- XO-3
- GJ 436

| Instr. ID | Data Set ID | Volume ID | Data Products |
|---|---|---|---|
| HRIV | DIF-X-HRIV-2-EPOXI-EXOPLANETS-V1.0 | EPXEXO_0001 | EDR: Raw transit observations grouped by target, then mid-observation date |
| | DIF-X-HRIV-3/4-EPOXI-EXOPLANETS-V1.0 | EPXEXO_0002 | RDR: Calibrated (RADREV and RAD) transit observations, grouped by target then mid- observation date |
| HRII | DIF-E-HRII-2-EPOXI-EARTH-OBS-V1.0 | EPXEAR_0001 | EDR: Raw Earth observations grouped by mid- observation date |
| | DIF-E-HRII-3/4-EPOXI-EARTH-OBS-V1.0 | EPXEAR_0002 | RDR: Calibrated (RADREV and RAD) Earth observations grouped by mid-observation date |
| HRIV | DIF-E-HRIV-2-EPOXI-EARTH-OBS-V1.0 | EPXEAR_0003 | EDR: Raw Earth observations grouped by mid-observation date |
| | DIF-E-HRIV-3/4-EPOXI-EARTH-OBS-V1.0 | EPXEAR_0004 | RDR: Calibrated (RADREV and RAD) Earth observations grouped by mid-observation date |
| MRI | DIF-E-MRI-2-EPOXI-EARTH-OBS-V1.0 | EPXEAR_0005 | EDR: Raw Earth observations grouped by mid-observation date |
| | DIF-E-MRI-3/4-EPOXI-EARTH-OBS-V1.0 | EPXEAR_0006 | RDR: Calibrated (RADREV and RAD) Earth observations grouped by mid-observation date |

### 3.2.3 DIXI

During the DIXI phase of the mission, the following types of data will be acquired and archived by instrument into DIXI-specific data sets of raw data (EDR) and calibrated data (RDR - RADREV, RAD, and IF depending on the instrument):

- Approach imaging of comet 103P/Hartley 2 by the HRIV and MRI CCDs beginning about 60 days before the encounter (E-60) and by the HRII spectrometer beginning about E-34 days,
- Imaging of comet 103P/Hartley 2 by all three instrument during the flyby encounter, and
- Lookback imaging of Hartley 2 by all three instrument extending to 21 days after the encounter (E+21).

| Instr. ID | Data Set ID | Volume ID | Data Products |
|---|---|---|---|
| HRII | DIF-C-HRII-2-EPOXI-HARTLEY2-V1.0 | EPXENC_0001 | EDR: Raw Hartley 2 observations grouped by mid- observation date |
| | DIF-C-HRII-3/4-EPOXI-HARTLEY2-V1.0 | EPXENC_0002 | RDR: Calibrated (RADREV and RAD) Hartley 2 observations grouped by mid-observation date |
| HRIV | DIF-C-HRIV-2-EPOXI-HARTLEY2-V1.0 | EPXENC_0003 | EDR: Raw Hartley 2 observations grouped by mid-observation date |

| | | | |
|---|---|---|---|
| | DIF-C-HRIV-3/4-EPOXI-HARTLEY2-V1.0 | EPXENC_0004 | RDR: Calibrated (RADREV, RAD, and I/F) Hartley 2 observations grouped by mid-observation date |
| MRI | DIF-C-MRI-2-EPOXI-HARTLEY2-V1.0 | EPXENC_0005 | EDR: Raw Hartley 2 observations grouped by mid-observation date |
| | DIF-C-MRIV-3/4-EPOXI-HARTLEY2-V1.0 | EPXENC_0006 | RDR: Calibrated (RADREV, RAD, and I/F) Hartley 2 observations grouped by mid-observation date |

During the DIXI phase of the mission, the MRI CCD and occasionally the HRIV CCD will be used as navigation cameras. Navigation (Nav) images of comet 103P/Hartley 2 acquired during approach and encounter will be archived in the raw and calibrated (RADREV) data sets listed below.

| Instr. ID | Data Set ID | Volume ID | Data Products |
|---|---|---|---|
| HRIV | DIF-C-HRIV-2-NAV-EPOXI-HARTLEY2-V1.0 | EPXNAV_0001 | EDR: Raw Nav images of Hartley 2 grouped by mid-observation date |
| | DIF-C-HRIV-3-NAV-EPOXI-HARTLEY2-V1.0 | EPXNAV_0002 | RDR: Calibrated (RADREV) Nav images of Hartley 2 grouped by mid-observation date |
| MRI | DIF-C-MRI-2-NAV-EPOXI-HARTLEY2-V1.0 | EPXNAV_0003 | EDR: Raw Nav images of Hartley 2 grouped by mid-observation date |
| | DIF-C-MRI-3-NAV-EPOXI-HARTLEY2-V1.0 | EPXNAV_0004 | RDR: Calibrated (RADREV) Nav images of Hartley 2 grouped by mid-observation date |

### 3.2.4 Higher-Level Data Sets for EPOCh and DIXI

Several higher-level products such instrument temperatures, photometry tables, shape models, and SPICE kernels are expected to be archived into the PDS. The proposed data sets are listed below. These data sets are typically simple and self-explanatory and are thus not described in this document.

| Instr. ID | Data Set ID | Volume ID | Data Products |
|---|---|---|---|
| HRII, HRIV, MRI | DIF-C/E/X-SPICE-6-EPOXI-V1.0 | EPXSP_0001 | SPICE kernels for the EPOXI mission. |
| HRII, HRIV, MRI | DIF-CAL-HRII/HRIV/MRI-6-EPOXI-TEMPS-V1.0 | EPXTMP_0001 | ASCII tables of averaged instrument sensor temperatures; If these products may be included in the raw and reduced science data sets if available. |
| HRIV | DIF-X-HRIV-4-EPOXI-EXOPLANETS-V1.0 | EPXEXO_0003 | Calibrated and cleaned (e.g., deconvolved) EPOCh observations of exoplanet transits |
| HRIV | DIF-X-HRIV-5-EPOXI-EXOPLANET-PHOTOM-V1.0 | EPXEXO_0004 | ASCII table of photometry derived from EPOCh observations of exoplanet transits |

| | | | |
|---|---|---|---|
| HRIV | DIF-X-HRIV-4-EPOCH-EARTH-OBS-V1.0 | EPXEAR_0007 | Calibrated and cleaned (e.g., deconvolved) EPOCh observations of Earth |
| HRIV | DIF-E-HRIV-5-EPOCH-EARTH-PHOTOM-V1.0 | EPXEAR_0008 | ASCII table of photometry derived from EPOCh observations of Earth |
| HRII | DIF-E-HRII-5-EPOCH-EARTH-SPECT-MAPS-V1.0 | EPXEAR_0009 | Spectral maps derived from HRII EPOCh observation of Earth |
| HRIV, MRI | DIF-C-HRIV/MRI-5-HARTLEY2-SHAPE-V1.0 | EPXENC_0007 | Shape model of 103P/Hartley 2 derived from HRIV and MRI images |
| HRII | DIF-C-HRII-5-HARTLEY2-THERMAL-MAPS-V1.0 | EPXENC_0008 | Temperature maps of the surface of 103P/Hartley 2 derived from HRII spectra |
| MRI | DIF-C-MRI-5-HARTLEY2-PHOTOMETRY-V1.0 | EPXENC_0009 | ASCII table of photometry derived from MRI science and Nav images of Hartley 2 |

# 4 Science Data Products

This section describes of the raw Level 2 and the calibrated Level 3 and 4 science data products included in the science data sets listed previously in sections 3.2.1, 3.2.2, and 3.2.3. We define science data products as the raw and calibrated HRII spectral and HRIV and MRI CCD visible image data acquired during EPOXI as well as the HRIV and MRI CCD images acquired for navigation purposes during the DIXI phase of the mission.

## *4.1 Overview of Data Products*

### 4.1.1 Raw FITS Data Product (EDR)

A raw science data product consists of a detached PDS label and a 2-dimensional FITS primary image (data) array and header with one 2-D image extension and header that provide a pixel-by-pixel quality map:

> **For HRII:** 2-D FITS spectral images (*.fit) in units of data number (raw counts) with one image extension for a pixel-by-pixel quality flags map (described in section 4.1.3). Fastest varying axis provides increasing wavelengths, from about 1.05 to about 4.8 microns. The slowest varying axis is in the spatial direction.
>
> **For HRIV, MRI:** 2-D FITS images (*.fit) in units of data number (raw counts) with one image extension for a pixel-by-pixel quality flags map (described in section 4.1.3).

Raw data are archived as received on the ground, either as uncompressed (i.e., never compressed) or compressed integer data. Image data could be compressed by means of a look-up table that converted 14-bit data to 8-bit values onboard the spacecraft. Raw, compressed data are stored in the FITS files as FITS files as 8-bit unsigned integers (i.e., exactly as received on the ground).

For the HRII instrument, uncompressed data consist of 14-bit signed integers stored in the FITS files as 16-bit signed integers with no offset. For the HRIV and MRI instruments, uncompressed data consist of 16-bit unsigned integers stored in the FITS files as 16-bit signed integers with an offset of 32768. The byte order for all FITS files in this archive is most significant bit first (MSB).

One raw product is archived is archived for data of the EPOCh and DIXI targets (extrasolar targets, Earth, and Hartley 2) as well as for calibration data (e.g., dark frames and standard stars) acquired by the HRII, HRIV, and MRI instruments.

### 4.1.2 Calibrated FITS Data Product (RDR)

A calibrated Level 3 or 4 science data product consists of a detached PDS label and a 2-dimensional FITS primary image data array and header with one 2-D image extension and header that provide a pixel-by-pixel quality map:

**HRII:** 2-D FITS spectral images with extensions for a quality flags map, a spectral wavelength map, a spectral bandwidth map, and a signal-to-noise map (*.fit). The extensions are describes in sections 4.1.3 through 4.1.6.

**HRIV, MRI:** 2-D FITS images with extensions for a quality flags map, and a signal-to-noise map, (*.fit). The extensions are describes in sections 4.1.3 through 4.1.6.

The calibration process, described in section 3.2.1, creates three types of reduced data products (that is, primary image arrays and accompanying extension) that are archived for EPOXI:

**RADREV:** These Level 3 uncleaned radiance image data, designated by the mnemonic 'RADREV', are provided in units of radiance as Watts/(meter**2 steradian micron). These data are considered reversible because the applied calibrations can be removed to get back to the original, raw data numbers. This type of calibrated product is archived for data of the EPOCh and DIXI targets (extrasolar targets, Earth, and Hartley 2) acquired by the HRII, HRIV, and MRI instruments mission.

**RAD:** These Level 4, irreversibly cleaned, radiance data are designated by the mnemonic 'RAD' and are provided in units of radiance as Watts/(meter**2 steradian micron). These data have been cleaned in such a way (interpolation over bad pixels, cosmic ray removal, etc.) such that the applied calibrations can not be backed out. This type of calibrated product is archived only for images of comet Hartley 2 acquired by the HRII, HRIV, and MRI instruments during the DIXI phase of the mission.

**IF:** These Level 4, irreversibly cleaned, reflectance data are designated by the mnemonic 'IF' and are unitless. An IF (I-over-F) image is generated by dividing the RAD (cleaned) image by the solar spectrum at the target body's heliocentric distance then multiplied by Pi. This type of calibrated product is archived only for images of comet Hartley 2 acquired by the HRIV and MRI instruments during the DIXI phase of the mission.

Calibrated spectral and CCD image data are stored as 32-bit IEEE signed real numbers in the FITS files. The byte order is most significant bit first (MSB).

### 4.1.3 Quality Flags Map (FITS Extension)

The Quality Flags map is the first FITS header and image extension in a raw or reduced science data product. Produced by the calibration pipeline for HRII, HRIV, and MRI data, this extension provides one byte of data quality flags or bits for each pixel in the primary image array. The image extension has the same dimensions as the primary image array.

Each of the one-byte pixels in this map is composed of eight bit flags. Each bit represents a specific characteristic about the corresponding pixel in the primary image. For a raw image, only the missing data value is turned on (set to 1). The remaining seven bits are set by the calibration pipeline for calibrated images only and are thus set to zero for all raw images. The bits are described below and are listed from the least-significant (0 or right-most) to most-significant (7 or left-most).

| MSB | | | | | | | LSB |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

0. Bad Pixel - This pixel is a known bad pixel.
1. Missing - The data for this pixel was not received from the spacecraft.
2. Despiked - This pixel was modified by the despiking routine.
3. Interpolated - This pixel was reclaimed by interpolating from its neighbors.
4. Some Saturated - The ***raw*** value for this pixel is above the point where some pixels are full-well saturated. For VIS instruments, this occurs at 11,000 DN, while for the IR spectrometer, this occurs at 8,000 DN.
5. Most Saturated - The ***raw*** value for this pixel is above the point where most pixels are full-well saturated. For VIS instruments, this occurs at 15,000 DN, while for the IR spectrometer, this occurs at 11,000 DN. Bit flag 4 (above) will also be set in this case because raw value exceeded the limit for that flag.
6. ADC Saturation - The ADC was saturated for this pixel.
7. Ultra Compressed - The ***raw*** value for this pixel was in a compression bin so large that the value contains very little information.

### 4.1.4 Signal-to-Noise Ratio Map (FITS Extension)

The Signal-to-Noise Ratio map is the last FITS header and image extension in a Level 3 or 4 calibrated science data product. Produced by the calibration pipeline for HRII, HRIV, and MRI data, this extension provides the signal-to-noise ratio as calculated by the pipeline for each pixel in the primary image array. The image extension has the same dimensions as the primary image array. Data values are stored as 32-bit IEEE real numbers. Section 3.2.1 describes the pipeline generates this extension.

### 4.1.5 IR Spectral Wavelength Map (FITS Extension)

The IR Spectral Wavelength map is the second FITS header and image extension in a Level 3 calibrated HRII science data product. Produced by the calibration pipeline only for HRII data, this extension provides the spectral registration or wavelength for each pixel in the primary image. This extension is required because of the wavelength for each pixel shifts with thermal changes within the instrument. The image extension has the same dimensions as the primary image array. Data values are stored as 32-bit IEEE real numbers. Section 3.2.1 describes the pipeline generates this extension.

### 4.1.6 IR Spectral Bandwidth Map (FITS Extension)

The IR Spectral Bandwidth map is the third FITS header and image extension in a Level 3 calibrated HRII science data product. Produced by the calibration pipeline only for HRII data, this extension provides the spectral bandwidth for each pixel in the primary image.

This extension is required because of the wavelength for each pixel shifts with thermal changes within the instrument. The image extension has the same dimensions as the primary image array. Data values are stored as 32-bit IEEE real numbers. Section 3.2.1 describes the pipeline generates this extension.

### 4.1.7 Pipeline Calibration Files

Files used by the pipeline to generate the calibrated science and navigation data products are produced by the EPOXI science team as a result of analyses of thermal-vacuum and in-flight calibration data from Deep Impact and in-flight calibrations from EPOXI. Nominally, the files used by the calibration pipeline to decompress compressed raw data will be included in the raw science data archive. Other files used by the pipeline to calibrate the raw data such as dark frames will be included if the final version is available when the raw data sets are produced.

Calibration files are provided as FITS image files (*.fit) or as flat ASCII tables (*.tab) with detached PDS labels and are packaged in the CALIB directory of the appropriate data sets.

#### 4.1.7.1 HRII Calibration Files

**ABSCALIR** - This subdirectory contains one table of the absolute calibration constants for each instrument (image) mode. The first column specifies the wavelength for the reading. The second column specifies the conversion factor for areas not under the anti-saturation filter. The last column contains the conversion factors for areas under the anti-saturation filter. Two identical files, one with a placeholder of '000' and another with '999' were created for the pipeline to allow existing processes to correctly execute.

**ADCLUT** - This subdirectory contains a look up table for the correcting for uneven bit weighting caused by the analog-to-digital conversion. The single table applies to all instrument modes. As of this archive, the corrections had not been derived. Therefore, the input pixel values are the same as the output values to prevent the automated calibration pipeline from changing the data.

**BADPIX** - This subdirectory contains maps that identify bad pixels for each instrument mode. These are master maps where a pixel is flagged bad it was determined to be bad in the four in-flight science calibrations. Bad pixels are set to a value of 1. Also, the reference rows and columns around the edges of the array are set to 1. Good pixels are set to 0.

**BIAS** - This subdirectory contains a dummy bias correction map for each instrument mode. All bias maps are set to zero to prevent the automated calibration pipeline from changing data.

**DARK** - This subdirectory contains dark frames for specific IR exposures. The exposure ID to which this dark frame can be applied is specified in the file name. The dark frames were created by averaging the frames within the specified exposure ID that were not on the target (i.e., background frames).

**DECOMPRS** - This subdirectory contains the four lossy look up tables used to decompress raw data.

**DRKMODEL** - This subdirectory contains master dark frames for each instrument mode.

**FLAT**- This subdirectory contains dummy flat fields for each instrument mode. Flat fields were derived from the linearity of each pixel. Some flats are dummies (all ones) as required by the calibration pipeline.

**LINDN** - This subdirectory contains mode-specific maps of the four coefficients used in a polynomial to linearize the raw data numbers. Mode 5 must use the mode 1 file. Modes 6 and 7 must use the mode 4 file.

**PSF** - This subdirectory contains a dummy point-spread function used by the calibration pipeline when one is not available. It is simply a centered delta function to prevent any changes to the data.

**SPECMAP** - This subdirectory contains temperature-dependent, pixel-by-pixel, spectral registration maps for each instrument mode. The first dimension provides the wavelength; the second provides the spectral resolution (delta wavelength). The temperature string in the file names refers to the temperature of the IR spectrometer for which a map is applicable.

**SUNSPEC** - This subdirectory contains two tables, based on different sources that provide the solar spectral irradiance at 1 AU for the given wavelengths.

**XTALK** - This subdirectory contains tables that specify the amount of gain from electronic cross talk that occurs between all possible combinations of the two quadrants of the IR array. There is one table for each instrument mode. The crosstalk is across IR quadrants is negligible, thus the table values are set to zero the automated calibration pipeline from changing data.

### 4.1.7.2 HRIV and MRI Calibration Files

**ABSCALVS** - This subdirectory contains one ASCII text table of the absolute calibration constants for each instrument (image) mode. specifies the constant for converting raw data numbers to units of radiance, W/(m**2 sr um). The second column specifies the constant for converting from units of radiance to units of reflectance (i.e., I-over-F or the observed radiance over the input solar radiance, unitless).

**ADCLUT** - This subdirectory contains a look up table for the correcting for uneven bit weighting caused by the analog-to-digital conversion. The single table applies to all instrument modes. As of this archive, the corrections had not been derived. Therefore, the input pixel values are the same as the output values to prevent the automated calibration pipeline from changing the data.

**BADPIX** - This subdirectory contains maps that identify bad pixels for each instrument mode. Bad pixels are set to a value of 1. Good pixels are set to 0. Pixels in the serial and parallel overclock columns and rows are flagged as good (0). For each image mode, there is one row of warm pixels near the top and bottom edge. These rows are flagged as bad (1).

**BIAS** - This subdirectory contains a bias correction map for each instrument mode.

**DECOMPRS** - This subdirectory contains the four lossy look up tables used to decompress raw data.

**DRKMODEL** - This subdirectory contains maps for modeling the dark signal for each instrument mode.

**FILTERS** - This subdirectory contains one transmission profile table each filter.

**FLAT** - This subdirectory contains flat fields for every combination instrument mode and filter.

**PSF** - This subdirectory contains a map of the point-spread function for each HRIV or MRI filter. For MRI, the PSF is simply a centered-delta function. For HRIV, the PSF files can be used to deconvolve an out-of-focus HRIV image.

**XTALK** - This subdirectory contains tables that specify the amount of gain from electronic cross talk that occurs between all possible combinations of the four quadrants of the CCD. There is one table for each instrument mode. However, after this data set was delivered to PDS for the review, it was discovered that the calibration pipeline used in incorrect tables, containing all zeros, for instrument modes 2 through 9. The tables for these modes should have been identical to the table for mode 1. However, this omission has a negligible effect (less than one percent) on the calibrated data.

## *4.2 Data Product Generation and Labeling*

### 4.2.1 Data Pipeline

All raw and calibrated science data products (FITS files and PDS labels) described in this document are generated a data and calibration pipeline that is maintained by the DI/EPOXI Science Data Center SDC at Cornell University. The pipeline takes raw telemetry with imbedded data, as downloaded from the DI flyby spacecraft, and constructs raw FITS spectral or visible image files and PDS labels. Images that were compressed onboard the spacecraft are received on the ground in the compressed format. The data pipeline keeps the associated raw FITS images in the same compressed format, and these data are archived in the *compressed* format.

Next, the data pipeline inputs the raw FITS files, decompresses any compressed data, calibrates the data through the RADREV, RAD, and I/F streams, and outputs calibrated data as FITS files (RADREV, RAD, and I/F). The calibration process is described below. For details about the SDC, the flow of data, and the calibration pipeline refer to the EPOXI Data Management and Archive Plan [3], Klaasen, et al. 2005 [5], and Klaasen, et al. 2008 [7].

Calibration files, such as bad pixel maps, are the result of the EPOXI science team's analysis of ground-based thermal-vacuum and in-flight calibration data from Deep Impact as well as in-flight calibrations acquired throughout the EPOXI mission. Calibration files are stored at the DI/EPOXI SDC and are used by the calibration portion of the pipeline. The files used by the pipeline to calibrate raw HRII, HRIV, and MRI data are included in the reduced EPOXI data sets.

PDS data labels are generated by the data pipeline using information stored in the FITS primary and extension headers. All PDS data labels are detached.

### 4.2.2 Calibration Process

The initial version of the calibration process for the EPOXI mission uses the final version of the pipeline used to calibrate data from the Deep Impact mission. The goal of the data calibration process for the HRII, HRIV, and MRI instruments is to:

- Convert the raw data numbers (DNs) returned from each pixel in each image or spectrum to absolute scientific units of scene radiance (reversible RADREVRAD or irreversible RAD).
- Convert HRIV and MRI radiance products (RAD) from the comet encounter to reflectance products (I/F).
- Determine from where in the scene or its surroundings the photons originated that produced the signal in each pixel.

The analysis of thermal-vacuum and in-flight calibration data from Deep Impact and the resulting calibration pipeline is presented in the DI Calibration Pipeline paper by Klaasen, et al. 2008 [7] and in the DI Anticipated Flight Data publication by Klaasen, et al. 2005 [5]. The following excerpt from the DI Instrument Calibration paper [7] is provided here as an overview of the processing:

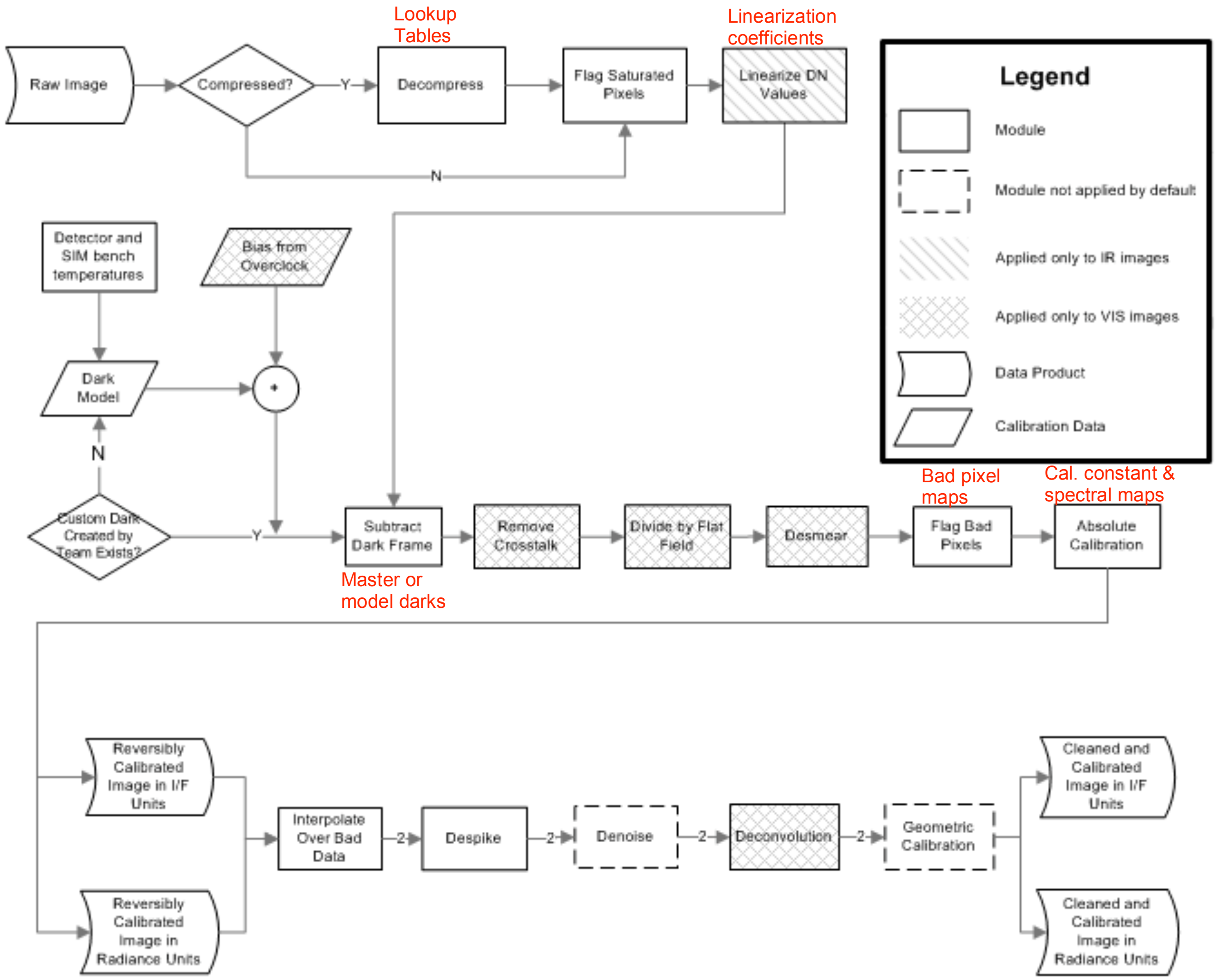


Figure 0 - A flowchart describing the data processing pipeline used to calibrate Deep Impact images. Some modules are not applied to all instruments. Input calibration files, such as the Look up tables for decompression, are identified by red text.

"6.0 <u>Pipeline Processing</u>

*6.1 Standard Steps Standard Steps*

For each image, there is a standard set of procedures and settings applied in our pipeline processing in order to calibrate the images automatically (see Figure 100). In general, these default settings are the best the science team has been able to derive for the data set as a whole and thus do not necessarily reflect the best possible processing for any particular image. However, there are some observations around encounter, especially with the IR spectrometer, that contain very valuable scientific information but are not processed optimally by the default settings. For these cases, the automated pipeline has the ability to specify special settings for particular observations.

The standard pipeline begins by decompressing the image if it was compressed on the spacecraft. Images can be compressed using one of four 14-bit to 8-bit look up tables optimized for different types of exposures. To uncompress the images, a reverse look up table is used which maps each 8-bit value to the average of all corresponding 14-bit values.

All saturated pixels are flagged in the quality map (Section 6.2 [7]). Then an IR image is linearized using the correction described in Section 5.3.1 [7]. A VIS image does not need this step because the instrument responds linearly (Section 4.3.1 [7]).

Next, a dark frame is subtracted from the image. If a dark frame has been created by the science team for the specific observation, then it is subtracted. Otherwise, a dark model is used to generate the frame (sections 4.3.3-VIS, 5.3.3-IR [7]).

After the dark subtraction, a VIS image undergoes a few extra processing steps not taken by every IR image. First, the electrical crosstalk (Section 4.3.7.5 [7]) is removed by subtracting a derived ghost frame. Each quadrant in this frame is a linear combination of rotated versions of the other three quadrants. Next, the image is divided by a flat field (Section 4.3.6 [7]) in order to account for variable responsivity across the detector. A flat field is only applied to unbinned IR images because the best binned-mode flat field does not seem to provide any noticeable improvement in SNR (and in the data products published as PDS version 1, unbinned IR images are not flat fielded either). Lastly, VIS CCD transfer smear is removed using the parallel overclock rows if the image was taken in modes one through six or a column averaging approximation if the image is in modes seven or eight (Section 4.3.4 [7]).

After bad pixels are flagged, the image is radiometrically calibrated to produce a radiance image in W/[$m^2$ sr um] and an I/F image. For a VIS image, this is simply done by dividing the image by integration time and then multiplying by the appropriate conversion factor derived in Section 4.3.5 [7] for the given filter and desired output. For an IR image, the procedure is more complicated as the absolute calibration is wavelength dependent, which in turn is temperature dependent. First, the wavelength and bandwidth for each pixel are calculated as described in Section 5.3.4 [7]. Then, each pixel is multiplied by the appropriate wavelength-dependent calibration factor (Section 5.3.6 [7]) and divided by integration time and the pixel's spectral bandwidth. Once this radiance image is created, a copy is converted to I/F by dividing by the solar spectrum at the target's distance from the sun and then multiplying by pi.

At this point, two reversible data products have been created, one radiance image and one I/F image, and copies are run through the rest of the pipeline, which performs a series of non-reversible steps. First, the data are interpolated over the bad pixels and gaps. For a VIS image, this interpolation is performed using thin plate splines anchored by the valid data around the edges of each hole. For an IR image, a linear interpolation is performed in the spatial dimension only.

Next, a despiking routine is applied in order to remove cosmic rays. This routine performs a sigma filter by calculating the median of each NxN box, where N is odd, and then replacing the central pixel with the median if it is more than M median deviations from the median. By default, both M and N are set to 3. The median deviation of a set S is defined as:

$$Med\,(\,|\,S - Med(S)\,|\,).$$

Lastly, a VIS image is deconvolved using the methods described in Section 4.2.3 [7]. This is especially important for the HRI-VIS instrument which is out of focus.

### *6.2 Calibration Quality Map*

Along with each calibrated image, a byte map is created that defines the data integrity for every pixel. For each byte in the map, representing one pixel, each bit acts as a flag that is set to 1 if the given criterion is met for that pixel. These flags are:

| MSB | | | | | | | LSB |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

0. Bad Pixel - This pixel is a known bad pixel.
1. Missing - The data for this pixel was not received from the spacecraft.
2. Despiked - This pixel was modified by the despiking routine.
3. Interpolated - This pixel has been reclaimed by interpolating from its neighbors.
4. Some Saturated - The raw value for this pixel is above the point where some pixels are full-well saturated. For VIS instruments, this occurs at 11,000 DN, while for the IR spectrometer, this occurs at 8,000 DN.
5. Most Saturated - This raw value for this pixel is above the point where most pixels are full-well saturated. For VIS instruments, this occurs at 15,000 DN, while for the IR spectrometer, this occurs at 11,000 DN.
6. ADC Saturation - The ADC was saturated for this pixel.
7. Ultra Compressed - The pixel was in a compression bin so large that the value contains very little information.

For example, if the pixel is bad and has been reclaimed by interpolation, the decimal value in the quality map will be $2^0 + 2^3 = 9$. In the normal FITS format for the calibrated image, this map exists as the first image extension.

### *6.3 Signal-to-Noise Ratio Map*

In order to provide more information to the end user, the last extension of the image contains a map estimating the signal to noise ratio for each pixel. The signal is taken to be the dark- and bias-subtracted image value in 14-bit DN, while the noise estimate consists of the root-sum-squared of three different noise sources: shot noise, read noise and quantization noise. The shot noise in 14-bit DN is defined as:

$$N_s = \mathrm{sqrt}\,(\,(\,Raw - Bias\,)\ /\ K\,)$$

where K is the gain in electrons/14-bit DN and is dependent on the instrument and mode, and *Raw* and *Bias* are in 14-bit DN. For the IR spectrometer, *Bias* is 0 by definition except in Mode 6. The quantization noise is defined as:

$$N_q = Q / \mathrm{sqrt}(12)$$

where Q is the quantization step in 14-bit DN. For uncompressed data, Q depends on the ADC performance of the instrument (see Sec. 4.3.7.3 and Sec. 5.3.8.3 [7]), while for compressed data, Q is set to the bin size in the decompression look up table that the pixel used or to the uncompressed Q value, whichever is larger. The parameter values needed for the noise calculation were determined from ground-based testing of the instruments and are shown in Table 20.

| **Instrument** | **K ($e/DN_{14}$)** | **Uncompressed Q ($DN_{14}$)** | **Read Noise ($DN_{14}$)** |
|---|---|---|---|
| IR Unbinned | 16 | 1 | 2.0 |
| IR Binned | 64 | 1 | 1.0 |
| HRI | 27.4 | 2 | 0.7 |
| MRI | 27.2 | 2 | 1.0 |
| ITS | 30.5 | 2 | 1.2 |

Table 20 - Noise parameters determined in ground tests of all instruments.

### *6.4 Spectral Registration Maps*

In an IR image product, the second and third extensions are pixel-by-pixel maps of the spectral registration for the image. The second extension contains the effective wavelength of the pixel, while the third extension contains the spectral bandwidth. The calculations of these values are described in Section 5.3.4 [7].

### *6.5 Optional Steps*

Beyond the automated calibration pipeline described in Section 6.1, a manual calibration can be performed where the user can specify his/her own settings and calibration files for each step. Also, any processing module can be disabled, and there are two extra ones that can be enabled. The first such module is a noise-reduction module that is applied after the despiking routine. This applies the BayesShrink wavelet thresholding algorithm with a robust mean noise estimator to remove some of the noise. The other step that can be enabled applies a rubber sheet geometric distortion correction. This is not normally applied as the optical distortion though the telescope is minimal."

See the instrument calibration document [7] for a detailed description of the image quality, spectral wavelength, spectral bandwidth, and signal-to-noise maps created by the pipeline and appended to the primary FITS image as image extensions.

### 4.2.3 Image Orientation and Pixel Readout Order

This section was excerpted from the submitted draft of the DI Calibration Pipeline paper by Klaasen, et al. 2008 [7].

In order to understand the data from the instruments at the level of calibrations, it is important to understand both the way in which pixels are read out from the detector and also the way in which they are stored in the resultant FITS/PDS images. Throughout this paper we identify the four physical quadrants of the detectors as A through D (or just A and B in the case of the IR detector, which only uses 2 of the quadrants on the physical detector). The nomenclature in Figures 1, 2, and 3 assumes the standard convention for displaying FITS files: the faster-varying index in the data file (for line samples) is displayed to the right and the slower varying index (for lines) is displayed up (in PDS images the directions are controlled by keywords, which for our images are set to match the standard FITS display). Thus, the first byte of the FITS/PDS file appears in the lower-left corner of the window and the last byte in the FITS/PDS file appears in the upper-right. All FITS/PDS archival images are structured to display a true image of the sky, with arbitrary rotation about the center of the image (ecliptic north is to the right in this particular image), rather than a mirror image of the sky. The image header information in the downlinked data is always written in the first 100 bytes of quadrant A.

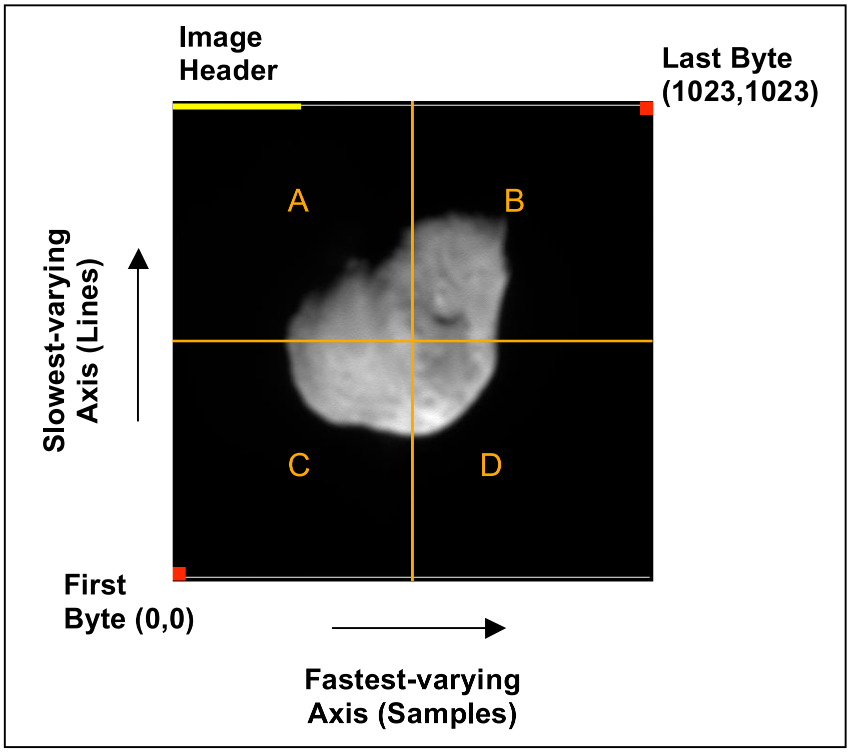


Figure 1 - A full-frame, HRI-VIS image taken shortly before impact, displayed with the FITS convention. This orientation reproduces a true sky image. The first and last bytes are those read from the FITS file and are not connected with the order of readout. Quadrants A, B, C and D noted throughout this paper are labeled in the image.

Figure 1 shows an inflight, visible image from HRI, in which the directions in the labels are referred to by the order of the bytes (pixels) in the archived data files. The images from the thermal-vacuum calibrations have the same orientation. For MRI, the different number of reflections in the optical path of the instruments lead to a right-left mirroring between the physical quadrants and the image of the sky and also a mirroring between the thermal-vacuum calibrations and the inflight data. Since the quadrant labeling refers to physical quadrants, the thermal-vacuum calibrations have the same orientation of the quadrants for all three instruments (A in upper left and D in lower right), but they have different orientations for inflight data, i.e., the inflight data for MRI have quadrant A in the upper right and quadrant D in the lower left for normally displayed FITS images. Thus the quadrants for inflight images from MRI are shown in Figure 2.

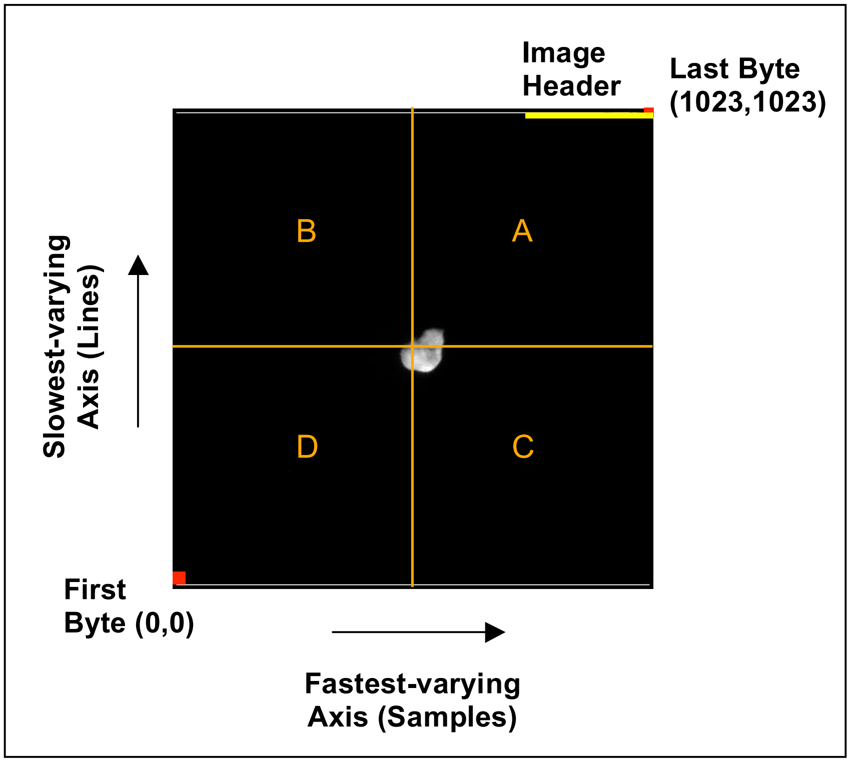


Figure 2 - A full-frame, MRI image taken at nearly the same time as the HRI-VIS image in Figure 1. Displayed with the FITS convention, a true sky image is reproduced. The first and last bytes are those read from the FITS file and are not connected with the order of readout. Quadrants A, B, C and D noted throughout this paper are labeled in the image.

The readout order of the pixels is independent of the order of bytes in the FITS images since each quadrant is read out independently in parallel, and the bytes are then rearranged into an image. The direction of the split-frame rapid transfer is up and down in Figures 1 and 2, symmetric about the centerline. This affects the smear of bright sources in short exposures. After shifting to the shielded region of the detector, the top and bottom rows are read out first (top and bottom of the relevant subframe when only a subframe is read), and in each of these rows the outermost pixels are read out first. The rows immediately above and below the centerline are read out last, and within these two rows, the pixels immediately adjacent to the centerline are read out last. The header information is overwritten on the first 100 bytes of quadrant A (upper left quadrant for HRI inflight images and upper right quadrant for in-flight images with MRI) after the image is constructed. Overclocked pixels and rows are read out after the true pixels, but they are moved to the outside of the FITS/PDS image to preserve the contiguity of the image in normal displays.

The situation for the IR spectrometer is shown in Figure 3. The normally displayed image, whether using the FITS standard display convention or displaying via the relevant PDS keywords, will have wavelength increasing from left to right and the long spatial dimension of the slit oriented vertically. The vertical spatial direction in the spectrometer image is the same as in the HRI visible image, terminator at the top and limb at the bottom for a spectrum at the time of Figure 1. There are only two quadrants used (as shown in Figure 4), although the actual detector has two additional quadrants that are not exposed to light and are not read out. The orientation is the same both for inflight data and for thermal-vacuum calibrations, with A is on the left in a standard FITS/PDS display and B is on the right. When the image is constructed, the header information is overwritten on the first 100 bytes of quadrant A.

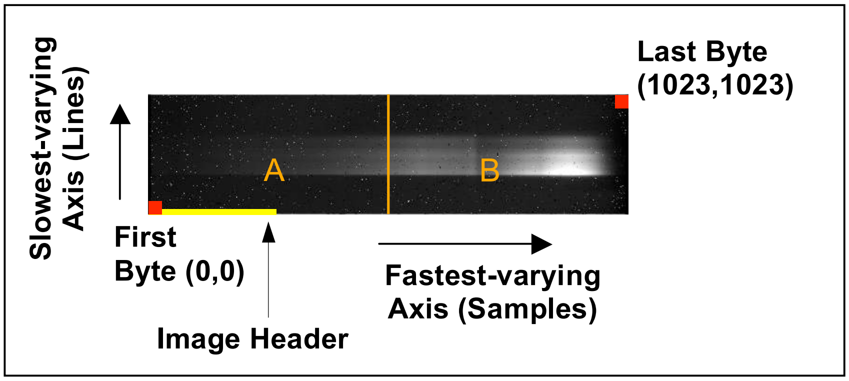


Figure 3 - A full-frame, HRIIR image taken shortly before impact, displayed with the FITS convention. For this FITS display, the wavelength increases as the fastest-varying axis increases to the right. The slowest-varying axis is the spatial direction along the slit. The first and last bytes are those read from the FITS file and are not connected with the order of readout. IR quadrants A and B noted throughout this paper are labeled in the image.

Since the IR detector is reset and read out on a pixel-by-pixel basis, the readout order affects the actual time at which a pixel is exposed, unlike the situation for the visible CCDs. Each pixel has the same exposure duration, but the exposure of the last pair of pixels read out does not start until one integration delay time plus ~2 ms before the first pair of pixels is read out . As with the lower half of the visible images, the bottom row is read out first, and within that row the outermost (leftmost and rightmost) pixels are read out first. The spectral row at the upper end of the slit in this standard display is read out last, and within that row the two pixels on either side of the center line are read out last. The header information is again written over the first 100 bytes of quadrant A, now in the lower left of a normal display.

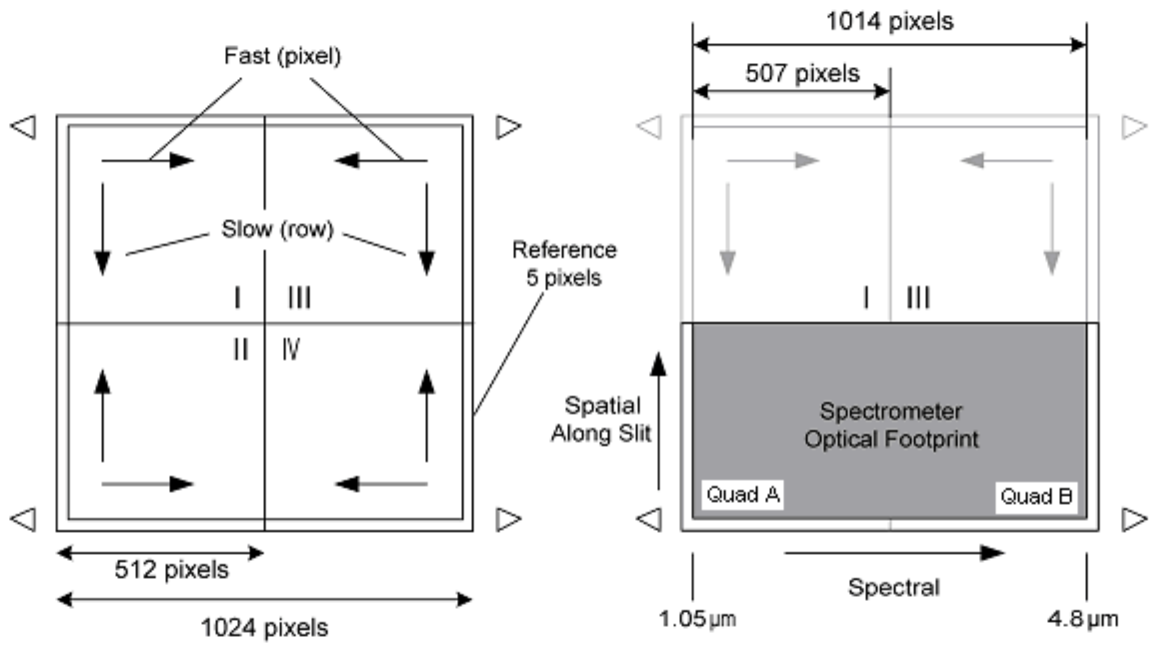


Figure 4 - IR focal plane array architecture ([4], used with permission). The left panel shows the architecture for the full IR FPA. The right panel shows the spectrometer mapping onto the FPA. Only Quads II (A) and IV (B) are used; Quads I and III are not used.

### 4.2.4 Data File Naming Conventions and Product IDs

The naming convention for the products in the data directory for the raw and calibrated data sets is:

iiYYMMDDHH_eeeeeee_nnn{_xx}.fit or .lbl

where:

- ii = instrument mneumonic: "hi" for the HRI IR Spectrometer, "hv" for the HRI Visible CCD, and "mv" for the MRI Visible CCD
- YYMMDDHH = Abbreviated UTC time stamp for the mid-point of the observation: YY is the last two digits of the year, MM is the month, DD is the day, and HH is the hour (00 to 24)
- eeeeeee = exposure ID
- nnn = image number with exposure ID
- xx = identifies the level of calibration: "rr" for RADREV, "r" for RAD, and "if" for I-over-F (reflectance); not used for RAW

This conventions guarantees unique file names within a PDS data set. The value for the PRODUCT_ID keyword in the PDS data labels is formed from the FITS file name where the period before the extension is replaced with an underscore character. PRODUCT_IDs are unique within each data set as required by PDS.

## *4.3 Standards Used in Data Product Generation*

### 4.3.1 PDS Standards

The version 3, PDS3, of the PDS Standards Reference [1] and revision E of the PDS Data Dictionary and the EPOXI Local Data Dictionary [2] were followed when generating the data products.

### 4.3.2 Time Standards

Times given in the PDS labels are UTC at the EPOXI spacecraft, unless otherwise specified.

### 4.3.3 Reference Frame Standards

PDS labels for raw and calibrated science and navigation FITS data products contain keywords that provide geometry-related values based on the inertial reference frame, Earth mean equator J2000 (EMEJ2000). The exception is the ECLIP_NORTH_CLOCK_ANGLE keyword that is in the Ecliptic J2000 frame (ECLIPJ2000). Definitions of geometry keywords found in the raw and calibrated science and navigation labels are found in section 4.2 of this document and explicitly refer the appropriate reference frames.

### 4.3.4 Image Orientation

For consistency, raw and calibrated science and navigation FITS images, as produced by the EPOXI data pipeline and analyzed by the science team, are stored in this PDS archive, and the LINE_DISPLAY_DIRECTION and SAMPLE_DISPLAY_DIRECTION keywords in the labels describe how the data must be displayed: Samples are displayed from left to right and lines from the bottom to the top, such that the first pixel read from the FITS file is displayed in the lower-left corner of a graphics window and the last pixel in the upper-right.

This orientation provides views "as seen" by the spacecraft and places ecliptic north approximately to the right and the sun towards the bottom for all images from the beginning of EPOXI through the approach and shield mode portions for the Hartley 2 encounter of DIXI. As the spacecraft comes out of shield mode, it will turn back and continue imaging the comet. Therefore, all DIXI lookback images have ecliptic north approximately to the left and the sun approximately towards the top. See section 4.3.2 for more information.

Also it is important to note that the slit of the HRII spectrometer is oriented vertically such that the top of the slit in an HRII image corresponds to the top of an HRIV or MRI image.

## *4.4 Sample PDS Labels*

This section provides sample PDS labels for raw and calibrated science data products for the HRII spectrometer and the HRIV and MRI CCDs.

### 4.4.1 Level 2 (Raw) HRII Science Data Product

The raw science data products for the HRII instrument have self-consistent formats. An example of a PDS label for a raw HRII FITS data file is provided below. Units for the primary image array are data number.

```
PDS_VERSION_ID   = PDS3
/***********************************/
/****** PDS LABEL NOT COMPLETE ******/
/***********************************/
RECORD_TYPE      = "FIXED_LENGTH"
RECORD_BYTES     = 2880
FILE_RECORDS     = 83

^HEADER = ("HI08052904_1001003_004.FIT",1)
^IMAGE = ("HI08052904_1001003_004.FIT",14)
^EXT_QUALITY_FLAGS_HEADER = ("HI08052904_1001003_004.FIT",60)
^EXT_QUALITY_FLAGS_IMAGE = ("HI08052904_1001003_004.FIT",61)
```

```
DATA_SET_ID          = "DIF-E-2-HRII-EPOXI-EARTH-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - IR SPECTROMETER"
INSTRUMENT_ID        = "HRII"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HI08052904_1001003_004_FIT"
PRODUCT_CREATION_TIME = 2008-07-29T20:59:05
PRODUCT_TYPE         = "RAW"

/***** TIME INFORMATION *****/
START_TIME           = 2008-05-29T04:21:03.984
EPOXI:IMAGE_MID_TIME = 2008-05-29T04:21:04.702
STOP_TIME            = 2008-05-29T04:21:05.420
START_JULIAN_DATE_VALUE = 2454615.68129609
MID_JULIAN_DATE_VALUE   = 2454615.68130440
STOP_JULIAN_DATE_VALUE  = 2454615.68131271
SPACECRAFT_CLOCK_START_COUNT      = "1/0265306167.104"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT  = "1/0265306168.032"
SPACECRAFT_CLOCK_STOP_COUNT       = "1/0265306168.216
EPOXI:EARTH_OBSERVER_MID_TIME     = UNK

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME           = "EPOCH"
EPOXI:MISSION_ACTIVITY_TYPE  = "EARTHOBS"
EPOXI:OBSERVATION_DESC       = "IR EARTH SCAN B RADIOMETRY; N/S SCANS 5B"
TARGET_NAME                  = "EARTH"
TARGET_DESC                  = "EARTH"
INSTRUMENT_MODE_ID           = 2
EPOXI:INSTRUMENT_MODE_NAME   = "BINSF1"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID          = "N/A"
EPOXI:OBSERVATION_ID   = "1001003"
EPOXI:IMAGE_NUMBER     = "004"
EPOXI:COMMANDED_IMAGE_COUNT = 8
FILTER_NUMBER          = "N/A"
FILTER_NAME            = "N/A"
CENTER_FILTER_WAVELENGTH    = "N/A"
EPOXI:INTEGRATION_DURATION  = 1435.6400000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 304.1247840 <K>
, 304.1247840 <K>
, 299.3939680 <K>
, 302.5192480 <K>
, 283.5592160 <K>
, 163.1479276 <K>
, 137.5605760 <K>
, 137.2787488 <K>
, 132.1110720 <K>
, 135.9330490 <K>
, 83.9405000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
```

```
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2128898 <V>
, 1.2052597 <V>
, 1.2162471 <V>
, 5.1249156 <V>
, 5.1233263 <V>
, 5.1098166 <V>
, 5.1058432 <V>
, 5.0335270 <V>
, -5.0287589 <V>
, 5.0120705 <V>
, -9.2021797 <V>
, 0.2421531 <V>
, 0.7374664 <V>
, 3.4035968 <V>
, UNK
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE   = "N/A"
VERTICAL_PIXEL_SCALE     = "UNK"

/***** GEOMETRY PARAMETERS *****/
NOTE                          = "
  Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
  system used to specify observational geometry.  Geometric parameters are
  based on the best available SPICE data at the time of product creation.
  Refer to the EPOXI SPICE archive for the most current observational
  geometry.  The observation midpoint was used to derive the geometry.
  All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG      = "BAD"
EPOXI:GEOMETRY_TYPE              = "PREDICTED"
SPICE_FILE_NAME                  = "UNK"
RIGHT_ASCENSION                  = "UNK"
DECLINATION                      = "UNK"
CELESTIAL_NORTH_CLOCK_ANGLE      = "UNK"
```

```
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = "UNK"
EPOXI:SUN_DIRECTION_CLOCK_ANGLE  = "UNK"
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = "UNK"
SOLAR_ELONGATION                 = "UNK"
PHASE_ANGLE                      = "UNK"
TARGET_CENTER_DISTANCE           = "UNK"
TARGET_HELIOCENTRIC_DISTANCE     = "UNK"
TARGET_GEOCENTRIC_DISTANCE       = "UNK"
EPOXI:SC_HELIOCENTRIC_DISTANCE   = "UNK"
EPOXI:SC_GEOCENTRIC_DISTANCE     = "UNK"
QUATERNION_DESC                  = "QUATERNION_DESC.ASC"
QUATERNION                       =
( "UNK"
, "UNK"
, "UNK"
, "UNK"
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
( "UNK"
, "UNK"
, "UNK"
)
EPOXI:TARGET_SC_POSITION_VECTOR   =
( "UNK"
, "UNK"
, "UNK"
)
EPOXI:TARGET_SC_VELOCITY_VECTOR   =
( "UNK"
, "UNK"
, "UNK"
)
TARGET_SUN_POSITION_VECTOR        =
( "UNK"
, "UNK"
, "UNK"
)
TARGET_SUN_VELOCITY_VECTOR        =
( "UNK"
, "UNK"
, "UNK"
)
EARTH_TARGET_POSITION_VECTOR      =
( "UNK"
, "UNK"
, "UNK"
)
EARTH_TARGET_VELOCITY_VECTOR      =
( "UNK"
, "UNK"
, "UNK"
)
SC_SUN_POSITION_VECTOR            =
( "UNK"
, "UNK"
, "UNK"
)
SC_EARTH_POSITION_VECTOR          =
( "UNK"
, "UNK"
, "UNK"
)
SUB_SPACECRAFT_LONGITUDE     = "UNK"
```

```
SUB_SPACECRAFT_LATITUDE      = "UNK"
SUB_SOLAR_LONGITUDE          = "UNK"
SUB_SOLAR_LATITUDE           = "UNK"
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE       = "N/A"
COORDINATE_SYSTEM_NAME       = "N/A"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HI0265306168_1001003_004.FIT"
PROCESSING_HISTORY_TEXT      = "RAW"

OBJECT     = HEADER
  BYTES              = 37440
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 13
  DESCRIPTION        = "FITS format defined in
     NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT             = IMAGE
  LINE_SAMPLES     = 512
  LINES            = 128
  SAMPLE_BITS      = 16
  SAMPLE_TYPE      = "MSB_INTEGER"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  OFFSET           = 0
  SCALING_FACTOR   = 1
  UNIT             = "DATA_NUMBER"
  EPOXI:DERIVED_MINIMUM            =  -126
  EPOXI:DERIVED_MAXIMUM            = 16168
  EPOXI:DERIVED_MEDIAN             =    986.0
  EPOXI:DERIVED_STANDARD_DEVIATION =    414.7
END_OBJECT         = IMAGE

OBJECT     = EXT_QUALITY_FLAGS_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension provides quality flags for
   each pixel in the primary image array.  Each of the one-byte pixels
   in this map is composed of eight bits.  Each bit represents a specific
   characteristic about the corresponding pixel in the primary image
   array.  For a raw image, only the bit for a missing data value is set
   (bit 1 below).  The remaining 7 bits apply only to a calibrated image
   and are thus set to zero for a raw image.  The bits are described below
   and are listed from the least-significant (0) to most-significant (7):
     0 = Bad
     1 = Data for this pixel was not received from the spacecraft or
         this pixel is one of the image header bytes.
     2 = Despiked
     3 = Interpolated
     4 = Partially saturated
     5 = Mostly saturated
     6 = ADC saturated
     7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT             = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES     = 512
```

```
  LINES            = 128
  SAMPLE_BITS      = 8
  SAMPLE_TYPE      = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  OFFSET           = 0
  SCALING_FACTOR   = 1
END_OBJECT         = EXT_QUALITY_FLAGS_IMAGE

END
```

### 4.4.2 Level 2 (Raw) HRIV/MRI Science Data Product

The raw science data products for the HRIV and MRI instruments have self-consistent formats. Therefore, only an example of a PDS label for a raw HRIV FITS data file is provided below. Units for the primary image array are data number.

Labels for raw HRIV and MRI navigation images are identical to the example below, except several keywords in the FITS header do not exist because the flight software did not include the information in the minimal image headers.

```
PDS_VERSION_ID   = PDS3
/************************************/
/****** PDS LABEL NOT COMPLETE ******/
/************************************/
RECORD_TYPE      = "FIXED_LENGTH"
RECORD_BYTES     = 2880
FILE_RECORDS     = 33

^HEADER = ("HV08071900_9200009_047.FIT",1)
^IMAGE = ("HV08071900_9200009_047.FIT",15)
^EXT_QUALITY_FLAGS_HEADER = ("HV08071900_9200009_047.FIT",27)
^EXT_QUALITY_FLAGS_IMAGE = ("HV08071900_9200009_047.FIT",28)

DATA_SET_ID          = "DIF-X-2-HRIV-EPOXI-EXOPLANETS-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - VISIBLE CCD"
INSTRUMENT_ID        = "HRIV"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HV08071900_9200009_047_FIT"
PRODUCT_CREATION_TIME = 2008-07-29T20:59:15
PRODUCT_TYPE         = "RAW"

/***** TIME INFORMATION *****/
START_TIME           = 2008-07-19T00:00:31.972
EPOXI:IMAGE_MID_TIME = 2008-07-19T00:00:56.972
STOP_TIME            = 2008-07-19T00:01:21.972
START_JULIAN_DATE_VALUE = 2454666.50037005
MID_JULIAN_DATE_VALUE   = 2454666.50065940
STOP_JULIAN_DATE_VALUE  = 2454666.50094876
SPACECRAFT_CLOCK_START_COUNT      = "1/0269696874.050"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT  = "1/0269696899.050"
SPACECRAFT_CLOCK_STOP_COUNT       = "1/0269696924.050"
EPOXI:EARTH_OBSERVER_MID_TIME     = 2008-07-19T00:03:44.593
```

```
/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME           = "EPOCH"
EPOXI:MISSION_ACTIVITY_DESC  = "EPOCH PHOTOMETRY"
EPOXI:OBSERVATION_DESC       = "EPOCH SCIENCE PHOTOMETRY HRIV PHOTOMETRY
SCIENCE"
TARGET_NAME                  = "WASP-3"
TARGET_DESC                  = "WASP-3"
INSTRUMENT_MODE_ID           = 5
EPOXI:INSTRUMENT_MODE_NAME   = "SF3S"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID          = "N/A"
EPOXI:OBSERVATION_ID   = "9200009"
EPOXI:IMAGE_NUMBER     = "047"
EPOXI:COMMANDED_IMAGE_COUNT = 125
FILTER_NUMBER          = 13
FILTER_NAME            = “CLEAR6”
CENTER_FILTER_WAVELENGTH    = 650 <NM>
EPOXI:INTEGRATION_DURATION  = 50000.5000000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 305.4484320 <K>
, 305.5097120 <K>
, 296.2441760 <K>
, 303.8919200 <K>
, 287.6282080 <K>
, 167.8455129 <K>
, 142.8807302 <K>
, 140.9054874 <K>
, 134.5060985 <K>
, 142.3818240 <K>
, 85.6805000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2064805 <V>
, 1.2125846 <V>
, 1.2049545 <V>
, 1.2162471 <V>
, 5.1257103 <V>
, 5.1233263 <V>
, 5.1098166 <V>
, 5.1050485 <V>
, 5.0351164 <V>
, -5.0287589 <V>
, 5.0144546 <V>
, -9.2051899 <V>
, 0.2445991 <V>
, 0.7411353 <V>
, 3.4035968 <V>
, UNK
```

```
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE   = "N/A"
VERTICAL_PIXEL_SCALE     = "N/A"

/***** GEOMETRY PARAMETERS *****/
NOTE                         = "
  Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
  system used to specify observational geometry.  Geometric parameters are
  based on the best available SPICE data at the time of product creation.
  Refer to the EPOXI SPICE archive for the most current observational
  geometry.  The observation midpoint was used to derive the geometry.
  All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG       = "OK"
EPOXI:GEOMETRY_TYPE               = "RECONSTRUCTED"
SPICE_FILE_NAME    = ( "NAIF0009.TLS",
                       "PCK00008.TPC",
                       "DIF_SCLKSCET.00029.TSC",
                       "DI_V17.TF",
                       "DIF_HRI_V10.TI",
                       "DIF_MRI_V10.TI",
                       "DIF_SC_050112_050809.BC",
                       "DIF_SC_050225_HIGHRATE.BC",
                       "DIF_SC_050704_HIGHRATE.BC",
                       "DIF_SC_2008_07_19.BC",
                       "JUP164_20YEAR.BSP",
                       "SPK_OD221_FULL.BSP" )
RIGHT_ASCENSION                  = 278.634313700 <DEG>
DECLINATION                      =  35.664184200 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE      = 128.6771 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = 135.2772 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE  =  67.5315 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = "N/A"
SOLAR_ELONGATION                 =  90.0424 <DEG>
PHASE_ANGLE                      =   0.005 <DEG>
TARGET_CENTER_DISTANCE           = "N/A"
TARGET_HELIOCENTRIC_DISTANCE     = "N/A"
TARGET_GEOCENTRIC_DISTANCE       = "N/A"
EPOXI:SC_HELIOCENTRIC_DISTANCE   = "N/A"
EPOXI:SC_GEOCENTRIC_DISTANCE     = "N/A"
QUATERNION_DESC                   = "QUATERNION_DESC.ASC"
QUATERNION                        =
(  0.770645000000
```

```
,  0.425281600000
, -0.166189100000
,  0.444548100000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
(  -6.379463374710e-07 <RAD/S>
,  -2.931862938810e-07 <RAD/S>
,   3.348453400460e-07 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR   =
( "N/A"
, "N/A"
, "N/A"
)
EPOXI:TARGET_SC_VELOCITY_VECTOR   =
( "N/A"
, "N/A"
, "N/A"
)
TARGET_SUN_POSITION_VECTOR        =
( "N/A"
, "N/A"
, "N/A"
)
TARGET_SUN_VELOCITY_VECTOR        =
( "N/A"
, "N/A"
, "N/A"
)
EARTH_TARGET_POSITION_VECTOR      =
( "N/A"
, "N/A"
, "N/A"
)
EARTH_TARGET_VELOCITY_VECTOR      =
( "N/A"
, "N/A"
, "N/A"
)
SC_SUN_POSITION_VECTOR            =
( "UNK"
, "UNK"
, "UNK"
)
SC_EARTH_POSITION_VECTOR          =
(  -43354627.823 <KM>
,  -25169617.788 <KM>
,   -3478461.858 <KM>
)
SUB_SPACECRAFT_LONGITUDE     = "N/A"
SUB_SPACECRAFT_LATITUDE      = "N/A"
SUB_SOLAR_LONGITUDE          = "N/A"
SUB_SOLAR_LATITUDE           = "N/A"
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE       = "N/A"
COORDINATE_SYSTEM_NAME       = "N/A"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HV0269696899_9200009_047.FIT"
PROCESSING_HISTORY_TEXT      = "RAW"

OBJECT     = HEADER
  BYTES              = 40320
```

```
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 14
  DESCRIPTION        = "FITS format defined in
     NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT             = IMAGE
  LINE_SAMPLES     = 128
  LINES            = 128
  SAMPLE_BITS      = 16
  SAMPLE_TYPE      = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  OFFSET           = 32768
  SCALING_FACTOR   = 1
  UNIT             = "DATA_NUMBER"
  EPOXI:DERIVED_MINIMUM            =   362
  EPOXI:DERIVED_MAXIMUM            =  1183
  EPOXI:DERIVED_MEDIAN             =    376.0
  EPOXI:DERIVED_STANDARD_DEVIATION =     14.0
END_OBJECT         = IMAGE

OBJECT     = EXT_QUALITY_FLAGS_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension provides quality flags for
   each pixel in the primary image array.  Each of the one-byte pixels
   in this map is composed of eight bits.  Each bit represents a specific
   characteristic about the corresponding pixel in the primary image
   array.  For a raw image, only the bit for a missing data value is set
   (bit 1 below).  The remaining 7 bits apply only to a calibrated image
   and are thus set to zero for a raw image.  The bits are described below
   and are listed from the least-significant (0) to most-significant (7):
     0 = Bad
     1 = Data for this pixel was not received from the spacecraft or
         this pixel is one of the image header bytes.
     2 = Despiked
     3 = Interpolated
     4 = Partially saturated
     5 = Mostly saturated
     6 = ADC saturated
     7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT             = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES     = 128
  LINES            = 128
  SAMPLE_BITS      = 8
  SAMPLE_TYPE      = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  OFFSET           = 0
  SCALING_FACTOR   = 1
END_OBJECT         = EXT_QUALITY_FLAGS_IMAGE

END
```

## 4.4.3 Level 3/4 (Calibrated) HRII Science Data Product

The calibrated science data products for the HRII instrument have self-consistent formats. An example of a PDS label for a reversible, calibrated HRII FITS science image in units of radiance (RADREV, not cleaned) is provided below. Labels for RAD (radiance units, cleaned) science images have the same format.

```
PDS_VERSION_ID   = PDS3
/***********************************/
/****** PDS LABEL NOT COMPLETE ******/
/***********************************/
RECORD_TYPE      = "FIXED_LENGTH"
RECORD_BYTES     = 2880
FILE_RECORDS     = 411

^HEADER = ("HI08052904_1001003_004_RR.FIT",1)
^IMAGE = ("HI08052904_1001003_004_RR.FIT",17)
^EXT_QUALITY_FLAGS_HEADER = ("HI08052904_1001003_004_RR.FIT",109)
^EXT_QUALITY_FLAGS_IMAGE = ("HI08052904_1001003_004_RR.FIT",110)
^EXT_WAVELENGTH_HEADER = ("HI08052904_1001003_004_RR.FIT",133)
^EXT_WAVELENGTH_IMAGE = ("HI08052904_1001003_004_RR.FIT",134)
^EXT_SPEC_BANDWIDTH_HEADER = ("HI08052904_1001003_004_RR.FIT",226)
^EXT_SPEC_BANDWIDTH_IMAGE = ("HI08052904_1001003_004_RR.FIT",227)
^EXT_SNR_HEADER = ("HI08052904_1001003_004_RR.FIT",319)
^EXT_SNR_IMAGE = ("HI08052904_1001003_004_RR.FIT",320)

DATA_SET_ID          = "DIF-E-3-HRII-EPOXI-EARTH-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - IR SPECTROMETER"
INSTRUMENT_ID        = "HRII"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HI08052904_1001003_004_RR_FIT"
PRODUCT_CREATION_TIME = 2008-07-29T20:59:05
PRODUCT_TYPE         = "RADIANCE_REVERSIBLE"

/***** TIME INFORMATION *****/
START_TIME           = 2008-05-29T04:21:03.984
EPOXI:IMAGE_MID_TIME = 2008-05-29T04:21:04.702
STOP_TIME            = 2008-05-29T04:21:05.420
START_JULIAN_DATE_VALUE = 2454615.68129609
MID_JULIAN_DATE_VALUE   = 2454615.68130440
STOP_JULIAN_DATE_VALUE  = 2454615.68131271
SPACECRAFT_CLOCK_START_COUNT      = "1/0265306167.104"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT  = "1/0265306168.032"
SPACECRAFT_CLOCK_STOP_COUNT       = "1/0265306168.216"
EPOXI:EARTH_OBSERVER_MID_TIME     = UNK

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME          = "EPOCH"
EPOXI:MISSION_ACTIVITY_TYPE  = "EARTHOBS"
EPOXI:OBSERVATION_DESC       = "IR EARTH SCAN B RADIOMETRY; N/S SCANS 5B"
TARGET_NAME                 = "EARTH"
INSTRUMENT_MODE_ID          = 2
EPOXI:INSTRUMENT_MODE_NAME   = "BINSF1"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID                = "N/A"
```

```
EPOXI:OBSERVATION_ID   = "1001003"
EPOXI:IMAGE_NUMBER     = "004"
EPOXI:COMMANDED_IMAGE_COUNT = 8
FILTER_NUMBER          = "N/A"
FILTER_NAME            = "N/A"
CENTER_FILTER_WAVELENGTH    = "N/A"
EPOXI:INTEGRATION_DURATION  = 1435.6400000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 304.1247840 <K>
, 304.1247840 <K>
, 299.3939680 <K>
, 302.5192480 <K>
, 283.5592160 <K>
, 163.1479276 <K>
, 137.5605760 <K>
, 137.2787488 <K>
, 132.1110720 <K>
, 135.9330490 <K>
, 83.9405000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2128898 <V>
, 1.2052597 <V>
, 1.2162471 <V>
, 5.1249156 <V>
, 5.1233263 <V>
, 5.1098166 <V>
, 5.1058432 <V>
, 5.0335270 <V>
, -5.0287589 <V>
, 5.0120705 <V>
, -9.2021797 <V>
, 0.2421531 <V>
, 0.7374664 <V>
, 3.4035968 <V>
, UNK
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
```

```
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE   = "N/A"
VERTICAL_PIXEL_SCALE     = UNK

/***** GEOMETRY PARAMETERS *****/
NOTE                         = "
  Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
  system used to specify observational geometry.  Geometric parameters are
  based on the best available SPICE data at the time of product creation.
  Refer to the EPOXI SPICE archive for the most current observational
  geometry.  The observation midpoint was used to derive the geometry.
  All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG       = "BAD"
EPOXI:GEOMETRY_TYPE               = "PREDICTED"
SPICE_FILE_NAME    = "UNK"
RIGHT_ASCENSION                  = "UNK"
DECLINATION                      = "UNK"
CELESTIAL_NORTH_CLOCK_ANGLE      = "UNK"
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = "UNK"
EPOXI:SUN_DIRECTION_CLOCK_ANGLE  = "UNK"
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = "UNK"
SOLAR_ELONGATION                 = "UNK"
PHASE_ANGLE                      = "UNK"
TARGET_CENTER_DISTANCE           = "UNK"
TARGET_HELIOCENTRIC_DISTANCE     = "UNK"
TARGET_GEOCENTRIC_DISTANCE       = "UNK"
EPOXI:SC_HELIOCENTRIC_DISTANCE   = "UNK"
EPOXI:SC_GEOCENTRIC_DISTANCE     = "UNK"
QUATERNION_DESC                   = "QUATERNION_DESC.ASC"
QUATERNION                        =
( "UNK"
, "UNK"
, "UNK"
, "UNK"
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
( "UNK"
, "UNK"
, "UNK"
)
EPOXI:TARGET_SC_POSITION_VECTOR   =
( "UNK"
, "UNK"
, "UNK"
)
EPOXI:TARGET_SC_VELOCITY_VECTOR   =
( "UNK"
, "UNK"
, "UNK"
)
TARGET_SUN_POSITION_VECTOR        =
( "UNK"
, "UNK"
, "UNK"
```

```
)
TARGET_SUN_VELOCITY_VECTOR        =
( "UNK"
, "UNK"
, "UNK"
)
EARTH_TARGET_POSITION_VECTOR      =
( "UNK"
, "UNK"
, "UNK"
)
EARTH_TARGET_VELOCITY_VECTOR      =
( "UNK"
, "UNK"
, "UNK"
)
SC_SUN_POSITION_VECTOR            =
( "UNK"
, "UNK"
, "UNK"
)
SC_EARTH_POSITION_VECTOR          =
( "UNK"
, "UNK"
, "UNK"
)
SUB_SPACECRAFT_LONGITUDE     = "UNK"
SUB_SPACECRAFT_LATITUDE      = "UNK"
SUB_SOLAR_LONGITUDE          = "UNK"
SUB_SOLAR_LATITUDE           = "UNK"
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE       = "N/A"
COORDINATE_SYSTEM_NAME       = "N/A"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HI0265306168_1001003_004_RR.FIT"
PROCESSING_HISTORY_TEXT      = "
FILEVERN=            1.1000000 / Version number of file format
PGMNAME = 'DICAL   '           / Program name that produced this file
PGMVERN =            5.0000000 / Version number of the above program
DATAQUAL=                 -999 / Data quality (1
TMPVLTUP=                    F / Physical temps and voltages updated (T/F)
TMPVLTV = '        '           / Valid date of physical temps, voltages used
SMOBENT =           -1.0000000 / Smoothed over time version of OPTBENT [K]
CMPRESSN=                    F / Decompression performed (T/F)
LUTTABLE= '        '           / Lossy lookup table/algorithm applied
CMPRMETH=                 -999 / Decompress method. 1
SATPIX  =                    T / Saturated pixels flagged (T/F)
SMSATVL =                 8000 / DN value where some pixels are saturated
MSTSATVL=                11000 / DN value where most pixels are saturated
ADCSATVL=                16383 / DN value where the ADC encoder is saturated
BITCORR =                    F / Uneven bit weighting corrected (T/F)
BITLUT  = '        '           / Bit weighting lookup table used
DARKCORR=                    T / Dark subtration (T/F)
DARKALG = 'MODEL   '           / Algorithm used to create dark
DARKFN  = 'HRIIR_050620_1_2.FIT' / File name for frame/model used
BIASFN  = '        '           / Filename of bias frame used
XTALK   =                    T / Electrical crosstalk removed (T/F)
XTALKFN = 'HRIIR_050112_2_2.FIT' / Filename of crosstalk gains used
GAINCORR=                    F / Quadrant Gain correction performed (T/F)
GAINFN  = '        '           / Filename of gain values used
FLATCORR=                    F / Flat fielded
FLATFILE= '        '           / Name of flat field applied
```

```
BPIXFL  =                    T / Bad pixels flagged (T/F)
BPIXFILE= 'HRIIR_050627_2_2_999.FIT' / Name of bad pixel map applied
CLEAN   =                    F / Cleaned/fill small gaps (T/F)
CLEANV  =                 -999 / Max filled gap size; -999999
CLNBAD  =                    F / Bad pixels cleaned
CLNMISS =                    F / Missing data cleaned
DESPIKE =                    F / Despiking applied (T/F)
DESPIKET=                 -999 / Despiking threshold used (sigma)
DESPIKEI=                 -999 / Number of iterations of despiking
DESPIKEB=                 -999 / Boxsize for despiking
DESPIKEM= '        '           / Metric used for despiking. Mean or Median
DENOISE =                    F / Denoising applied (T/F)
DENOISEV= '        '           / Denoise parameter applied
DECON   =                    F / Deconvolution performed (T/F)
DECONPSF= '        '           / Deconvolution psf used
DECONALG= '        '           / Deconvolution algorithm used
DECONV  = '        '           / Deconvolution algorithm-specific parameter
LINEARIZ=                    T / Linearization applied (T/F)
LINAC0  =            0.0000000 / Quad A additive constant for linearization
LINAC1  = 'HRIIR_050115_3_2.FIT' / Quad A coefficient for x term
LINAC2  = 'HRIIR_050115_3_2.FIT' / Quad A coefficient for x-squared term
LINAC3  = 'HRIIR_050115_3_2.FIT' / Quad A coefficient for x-cubed term
LINAC4  =       -999.000000000 / Quad A coefficient for x-4th term
LINBC0  =            0.0000000 / Quad B additive constant for linearization
LINBC1  = 'HRIIR_050115_3_2.FIT' / Quad B coefficient for x term
LINBC2  = 'HRIIR_050115_3_2.FIT' / Quad B coefficient for x-squared term
LINBC3  = 'HRIIR_050115_3_2.FIT' / Quad B coefficient for x-cubed term
LINBC4  =       -999.000000000 / Quad B coefficient for x-4th term
MDARKVER=              2.00000 / Master dark frame version
DRKPMODE=                    0 / Mode of the previous set taken
DARKISG =           -0.9990000 / Inter-sequence gap [msec]
DARKA0  =   30060000000.0000000 / Dark level temp coef A_0
DARKA1  =        -3384.4000000 / Dark level temp coef A_1
DARKB0  =      65630000.0000000 / Dark level temp coef B_0
DARKB1  =        -2002.0000000 / Dark level temp coef B_1
DARKC0  =            0.0583000 / Dark level temp coef C_0
DRKTMSCL=            1.0000000 / Dark scaling factor for time dependency
DARKPLAT=                    T / Dark plateau reached
DARKMSCL=         -999.0000000 / Manually derived scaling factor
CALCORR =                    T / Calibration Applied (T/F)
CALCONST=         -999.0000000 / Calibration Constant Applied
CALNUMB0=                    0 / Number of ZERO calibration factors found
CALMAP1 = 'HRIIR_050112_9_2_999.FIT' / Calibration constant map interped (1)
CALMAP2 = 'HRIIR_050112_9_2_000.FIT' / Calibration constant map interped (2)
SPECMAP1= '        '           / Spectral map interpolated over (1)
SPECMAP2= '        '           / Spectral map interpolated over (2)
HLUTFN  = '        '           / H lambda lookup table used
"

/***** IMAGE STATISTICS *****/
EPOXI:BAD_PIXEL_COUNT               = 4798
EPOXI:MISSING_PIXEL_COUNT           = 50
EPOXI:DESPIKED_PIXEL_COUNT          = 0
EPOXI:INTERPOLATED_PIXEL_COUNT      = 0
EPOXI:PARTIAL_SATURATED_PIXEL_COUNT = 16
EPOXI:SATURATED_PIXEL_COUNT         = 10
EPOXI:ADC_SATURATED_PIXEL_COUNT     = 0
EPOXI:ULTRA_COMPRESSED_PIXEL_COUNT  = 0

OBJECT     = HEADER
  BYTES              = 46080
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
```

```
  RECORDS            = 16
  DESCRIPTION        = "FITS format defined in
     NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT             = IMAGE
  LINE_SAMPLES     = 512
  LINES            = 128
  SAMPLE_BITS      = 32
  SAMPLE_TYPE      = "IEEE_REAL"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT             = "W/[m^2 sr um]"
  EPOXI:MINIMUM            = -1.70204000000e+01
  EPOXI:MAXIMUM            = 1.58491000000e+02
  EPOXI:MEDIAN             = -6.84000000000e-03
  EPOXI:STANDARD_DEVIATION = 3.06537000000e+00
END_OBJECT         = IMAGE

OBJECT     = EXT_QUALITY_FLAGS_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension provides quality flags for
   each pixel in the primary image array.  Each of the one-byte pixels
   in this map is composed of eight bits.  Each bit represents a specific
   characteristic about the corresponding pixel in the primary image
   array.  For a raw image, only the bit for a missing data value is set
   (bit 1 below).  The remaining 7 bits apply only to a calibrated image
   and are thus set to zero for a raw image.  The bits are described below
   and are listed from the least-significant (0) to most-significant (7):
     0 = Bad
     1 = Data for this pixel was not received from the spacecraft or
         this pixel is one of the image header bytes.
     2 = Despiked
     3 = Interpolated
     4 = Partially saturated
     5 = Mostly saturated
     6 = ADC saturated
     7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT             = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES     = 512
  LINES            = 128
  SAMPLE_BITS      = 8
  SAMPLE_TYPE      = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT         = EXT_QUALITY_FLAGS_IMAGE

OBJECT     = EXT_WAVELENGTH_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension provides the spectral
   wavelength for each pixel in the primary image array."
END_OBJECT = EXT_WAVELENGTH_HEADER
```

```
OBJECT              = EXT_WAVELENGTH_IMAGE
  LINE_SAMPLES      = 512
  LINES             = 128
  SAMPLE_BITS       = 32
  SAMPLE_TYPE       = "IEEE_REAL"
  AXIS_ORDER_TYPE   = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT              = "MICROMETER"
END_OBJECT          = EXT_WAVELENGTH_IMAGE

OBJECT     = EXT_SPEC_BANDWIDTH_HEADER
  BYTES               = 2880
  HEADER_TYPE         = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS             = 1
  DESCRIPTION         = "This extension provides the spectral
   bandwidth for each pixel in the primary image array."
END_OBJECT = EXT_SPEC_BANDWIDTH_HEADER

OBJECT              = EXT_SPEC_BANDWIDTH_IMAGE
  LINE_SAMPLES      = 512
  LINES             = 128
  SAMPLE_BITS       = 32
  SAMPLE_TYPE       = "IEEE_REAL"
  AXIS_ORDER_TYPE   = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT              = "MICROMETER"
END_OBJECT          = EXT_SPEC_BANDWIDTH_IMAGE

OBJECT     = EXT_SNR_HEADER
  BYTES               = 2880
  HEADER_TYPE         = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS             = 1
  DESCRIPTION         = "This extension is the signal-to-noise ratio
   for each pixel in the primary image array."
END_OBJECT = EXT_SNR_HEADER

OBJECT              = EXT_SNR_IMAGE
  LINE_SAMPLES      = 512
  LINES             = 128
  SAMPLE_BITS       = 32
  SAMPLE_TYPE       = "IEEE_REAL"
  AXIS_ORDER_TYPE   = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT          = EXT_SNR_IMAGE

END
```

### 4.4.4 Level 3/4 (Calibrated) HRIV/MRI Science Data Product

The calibrated science data products for the HRIV and MRI instruments have self-consistent formats. Therefore, only an example of a PDS label for reversible, calibrated HRIV FITS science image in units of radiance (RADREV, not cleaned) is provided below. Labels for RAD (radiance units, cleaned) and I-over-F (unitless irradiance, cleaned) science images have the same format.

Labels for reduced HRIV and MRI navigation images are identical to the example below, except several keywords in the FITS header do not exist because the flight software did not include the information in the minimal image headers.

```
PDS_VERSION_ID   = PDS3
/***********************************/
/****** PDS LABEL NOT COMPLETE ******/
/***********************************/
RECORD_TYPE      = "FIXED_LENGTH"
RECORD_BYTES     = 2880
FILE_RECORDS     = 71

^HEADER = ("HV08071900_9200009_047_RR.FIT",1)
^IMAGE = ("HV08071900_9200009_047_RR.FIT",18)
^EXT_QUALITY_FLAGS_HEADER = ("HV08071900_9200009_047_RR.FIT",41)
^EXT_QUALITY_FLAGS_IMAGE = ("HV08071900_9200009_047_RR.FIT",42)
^EXT_SNR_HEADER = ("HV08071900_9200009_047_RR.FIT",48)
^EXT_SNR_IMAGE = ("HV08071900_9200009_047_RR.FIT",49)

DATA_SET_ID          = "DIF-X-3-HRIV-EPOXI-EXOPLANETS-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - VISIBLE CCD"
INSTRUMENT_ID        = "HRIV"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HV08071900_9200009_047_RR_FIT"
PRODUCT_CREATION_TIME = 2008-07-29T20:59:15
PRODUCT_TYPE         = "RADIANCE_REVERSIBLE"

/***** TIME INFORMATION *****/
START_TIME           = 2008-07-19T00:00:31.972
EPOXI:IMAGE_MID_TIME = 2008-07-19T00:00:56.972
STOP_TIME            = 2008-07-19T00:01:21.972
START_JULIAN_DATE_VALUE = 2454666.50037005
MID_JULIAN_DATE_VALUE   = 2454666.50065940
STOP_JULIAN_DATE_VALUE  = 2454666.50094876
SPACECRAFT_CLOCK_START_COUNT      = "1/0269696874.050"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT  = "1/0269696899.050"
SPACECRAFT_CLOCK_STOP_COUNT       = "1/0269696924.050"
EPOXI:EARTH_OBSERVER_MID_TIME     = 2008-07-19T00:03:44.593

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME           = "EPOCH"
EPOXI:MISSION_ACTIVITY_TYPE  = "EPOCH PHOTOMETRY"
EPOXI:OBSERVATION_DESC       = "EPOCH SCIENCE PHOTOMETRY HRIV PHOTOMETRY
SCIENCE"
TARGET_NAME                  = "WASP-3"
INSTRUMENT_MODE_ID           = 5
EPOXI:INSTRUMENT_MODE_NAME   = "SF3S"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID          = "N/A"
EPOXI:OBSERVATION_ID   = "9200009"
EPOXI:IMAGE_NUMBER     = "047"
EPOXI:COMMANDED_IMAGE_COUNT = 125
FILTER_NUMBER          = 13
FILTER_NAME            = CLEAR6
CENTER_FILTER_WAVELENGTH    = 650 <NM>
EPOXI:INTEGRATION_DURATION  = 50000.5000000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
```

```
INSTRUMENT_TEMPERATURE =
( 305.4484320 <K>
, 305.5097120 <K>
, 296.2441760 <K>
, 303.8919200 <K>
, 287.6282080 <K>
, 167.8455129 <K>
, 142.8807302 <K>
, 140.9054874 <K>
, 134.5060985 <K>
, 142.3818240 <K>
, 85.6805000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2064805 <V>
, 1.2125846 <V>
, 1.2049545 <V>
, 1.2162471 <V>
, 5.1257103 <V>
, 5.1233263 <V>
, 5.1098166 <V>
, 5.1050485 <V>
, 5.0351164 <V>
, -5.0287589 <V>
, 5.0144546 <V>
, -9.2051899 <V>
, 0.2445991 <V>
, 0.7411353 <V>
, 3.4035968 <V>
, UNK
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)
```

```
/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE   = "N/A"
VERTICAL_PIXEL_SCALE     = "N/A"

/***** GEOMETRY PARAMETERS *****/
NOTE                         = "
  Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
  system used to specify observational geometry.  Geometric parameters are
  based on the best available SPICE data at the time of product creation.
  Refer to the EPOXI SPICE archive for the most current observational
  geometry.  The observation midpoint was used to derive the geometry.
  All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG       = "OK"
EPOXI:GEOMETRY_TYPE               = "RECONSTRUCTED"
SPICE_FILE_NAME    = ( "NAIF0009.TLS",
                       "PCK00008.TPC",
                       "DIF_SCLKSCET.00029.TSC",
                       "DI_V17.TF",
                       "DIF_HRI_V10.TI",
                       "DIF_MRI_V10.TI",
                       "DIF_SC_050112_050809.BC",
                       "DIF_SC_050225_HIGHRATE.BC",
                       "DIF_SC_050704_HIGHRATE.BC",
                       "DIF_SC_2008_07_19.BC",
                       "JUP164_20YEAR.BSP",
                       "SPK_OD221_FULL.BSP" )
RIGHT_ASCENSION                  = 278.634313700 <DEG>
DECLINATION                      =  35.664184200 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE      = 128.6771 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = 135.2772 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE  =  67.5315 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = "N/A"
SOLAR_ELONGATION                 =  90.0424 <DEG>
PHASE_ANGLE                      =   0.005 <DEG>
TARGET_CENTER_DISTANCE           = "N/A"
TARGET_HELIOCENTRIC_DISTANCE     = "N/A"
TARGET_GEOCENTRIC_DISTANCE       = "N/A"
EPOXI:SC_HELIOCENTRIC_DISTANCE   = "N/A"
EPOXI:SC_GEOCENTRIC_DISTANCE     = "N/A"
QUATERNION_DESC                   = "QUATERNION_DESC.ASC"
QUATERNION                        =
(  0.770645000000
,  0.425281600000
, -0.166189100000
,  0.444548100000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
(  -6.379463374710e-07 <RAD/S>
,  -2.931862938810e-07 <RAD/S>
,   3.348453400460e-07 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR   =
( "N/A"
, "N/A"
, "N/A"
)
EPOXI:TARGET_SC_VELOCITY_VECTOR   =
( "N/A"
, "N/A"
, "N/A"
)
TARGET_SUN_POSITION_VECTOR        =
```

```
( "N/A"
, "N/A"
, "N/A"
)
TARGET_SUN_VELOCITY_VECTOR        =
( "N/A"
, "N/A"
, "N/A"
)
EARTH_TARGET_POSITION_VECTOR      =
( "N/A"
, "N/A"
, "N/A"
)
EARTH_TARGET_VELOCITY_VECTOR      =
( "N/A"
, "N/A"
, "N/A"
)
SC_SUN_POSITION_VECTOR            =
( "UNK"
, "UNK"
, "UNK"
)
SC_EARTH_POSITION_VECTOR          =
(  -43354627.823 <KM>
,  -25169617.788 <KM>
,   -3478461.858 <KM>
)
SUB_SPACECRAFT_LONGITUDE     = "N/A"
SUB_SPACECRAFT_LATITUDE      = "N/A"
SUB_SOLAR_LONGITUDE          = "N/A"
SUB_SOLAR_LATITUDE           = "N/A"
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE       = "N/A"
COORDINATE_SYSTEM_NAME       = "N/A"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HV0269696899_9200009_047_RR.FIT"
PROCESSING_HISTORY_TEXT      = "
FILEVERN=            1.1000000 / Version number of file format
PGMNAME = 'DICAL   '           / Program name that produced this file
PGMVERN =            5.0000000 / Version number of the above program
DATAQUAL=                 -999 / Data quality (1
TMPVLTUP=                    F / Physical temps and voltages updated (T/F)
TMPVLTV = '        '           / Valid date of physical temps, voltages used
SMOBENT =           -1.0000000 / Smoothed over time version of OPTBENT [K]
CMPRESSN=                    F / Decompression performed (T/F)
LUTTABLE= '        '           / Lossy lookup table/algorithm applied
CMPRMETH=                 -999 / Decompress method. 1
SATPIX  =                    T / Saturated pixels flagged (T/F)
SMSATVL =                11000 / DN value where some pixels are saturated
MSTSATVL=                15000 / DN value where most pixels are saturated
ADCSATVL=                16383 / DN value where the ADC encoder is saturated
BITCORR =                    F / Uneven bit weighting corrected (T/F)
BITLUT  = '        '           / Bit weighting lookup table used
DARKCORR=                    T / Dark subtration (T/F)
DARKALG = 'MODEL   '           / Algorithm used to create dark
DARKFN  = 'HRIVIS_020601_2_5.FIT' / File name for frame/model used
BIASFN  = 'SERIAL OVERCLOCK'    / Filename of bias frame used
XTALK   =                    T / Electrical crosstalk removed (T/F)
XTALKFN = 'HRIVIS_050112_2_5.FIT' / Filename of crosstalk gains used
GAINCORR=                    F / Quadrant Gain correction performed (T/F)
```

```
GAINFN  = '        '            / Filename of gain values used
FLATCORR=                     T / Flat fielded
FLATFILE= 'HRIVIS_050701_1_5_6.FIT' / Name of flat field applied
BPIXFL  =                     T / Bad pixels flagged (T/F)
BPIXFILE= 'HRIVIS_020601_2_5_999.FIT' / Name of bad pixel map applied
CLEAN   =                     F / Cleaned/fill small gaps (T/F)
CLEANV  =                  -999 / Max filled gap size; -999999
CLNBAD  =                     F / Bad pixels cleaned
CLNMISS =                     F / Missing data cleaned
DESPIKE =                     F / Despiking applied (T/F)
DESPIKET=                  -999 / Despiking threshold used (sigma)
DESPIKEI=                  -999 / Number of iterations of despiking
DESPIKEB=                  -999 / Boxsize for despiking
DESPIKEM= '        '            / Metric used for despiking. Mean or Median
DENOISE =                     F / Denoising applied (T/F)
DENOISEV= '        '            / Denoise parameter applied
DECON   =                     F / Deconvolution performed (T/F)
DECONPSF= '        '            / Deconvolution psf used
DECONALG= '        '            / Deconvolution algorithm used
DECONV  = '        '            / Deconvolution algorithm-specific parameter
SMEAR   =                     T / Frame-transfer smear removed (T/F)
SMEARV  = 'POC ROWS'            / Smear removal algorithm applied
RADCAL  =                     T / Radiance calibration applied (T/F)
RADCALV =             0.0001175 / Rad cal constant used [W/(m^2 sr um)/(DN/s)]
RADCALW =                653.00 / Radiance calib - wavelength used [nm]
IOFCAL  =                     F / I/F calibration applied (T/F)
IOFCALV =         -999.0000000 / I/F cal constant used [W/(m^2 sr um) @ 1 AU]
IOFCALW = '        '            / I/F calib - wavelength used [nm]
IOFCALD =         -999.0000000 / I/F calib - Distance used [AU]
GEOMCAL =                     F / Geometric calibration performed (T/F)
GEOMFILE= '        '            / File used for geometric calibration
"

/***** IMAGE STATISTICS *****/
EPOXI:BAD_PIXEL_COUNT               = 256
EPOXI:MISSING_PIXEL_COUNT           = 50
EPOXI:DESPIKED_PIXEL_COUNT          = 0
EPOXI:INTERPOLATED_PIXEL_COUNT      = 0
EPOXI:PARTIAL_SATURATED_PIXEL_COUNT = 13
EPOXI:SATURATED_PIXEL_COUNT         = 2
EPOXI:ADC_SATURATED_PIXEL_COUNT     = 0
EPOXI:ULTRA_COMPRESSED_PIXEL_COUNT  = 0

OBJECT      = HEADER
  BYTES              = 48960
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 17
  DESCRIPTION        = "FITS format defined in
     NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT             = IMAGE
  LINE_SAMPLES     = 128
  LINES            = 128
  SAMPLE_BITS      = 32
  SAMPLE_TYPE      = "IEEE_REAL"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT             = "W/[m^2 sr um]"
  EPOXI:MINIMUM            = -1.43000000000e-05
  EPOXI:MAXIMUM            = 1.81000000000e-03
```

```
  EPOXI:MEDIAN             = 5.00000000000e-06
  EPOXI:STANDARD_DEVIATION = 3.21000000000e-05
END_OBJECT         = IMAGE

OBJECT     = EXT_QUALITY_FLAGS_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension provides quality flags for
   each pixel in the primary image array.  Each of the one-byte pixels
   in this map is composed of eight bits.  Each bit represents a specific
   characteristic about the corresponding pixel in the primary image
   array.  For a raw image, only the bit for a missing data value is set
   (bit 1 below).  The remaining 7 bits apply only to a calibrated image
   and are thus set to zero for a raw image.  The bits are described below
   and are listed from the least-significant (0) to most-significant (7):
     0 = Bad
     1 = Data for this pixel was not received from the spacecraft or
         this pixel is one of the image header bytes.
     2 = Despiked
     3 = Interpolated
     4 = Partially saturated
     5 = Mostly saturated
     6 = ADC saturated
     7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT             = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES     = 128
  LINES            = 128
  SAMPLE_BITS      = 8
  SAMPLE_TYPE      = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT         = EXT_QUALITY_FLAGS_IMAGE

OBJECT     = EXT_SNR_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension is the signal-to-noise ratio
   for each pixel in the primary image array."
END_OBJECT = EXT_SNR_HEADER

OBJECT             = EXT_SNR_IMAGE
  LINE_SAMPLES     = 128
  LINES            = 128
  SAMPLE_BITS      = 32
  SAMPLE_TYPE      = "IEEE_REAL"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT         = EXT_SNR_IMAGE

END
```

## 4.5 PDS Object and Keyword Definitions

This section provides definitions for the objects and keywords found in the PDS labels for raw and reduced HRII spectral image FITS data. Definitions are ordered as in the label examples provided above.

All time- and geometry-related keyword values are based on the time at the spacecraft, except EARTH_RECEIVED_TIME that provides the UTC of the image mid-time for an observer on Earth. All values for geometry-related keywords were calculated for the mid-point of an image at the spacecraft ***except for "target-to-sun" and "earth-observer-to-target" keywords***. The values for target-to-sun were calculated for the time (with respect to image mid-time) when the light left the sun while the values for earth-observer-to-target were calculated for the time when the light left the target.

| PDS Keyword or Object | Definition |
|---|---|
| PDS_VERSION_ID | Represents the version number of the PDS standards documents that is valid when a data product label is created. PDS3 is used for Deep Impact data products. |
| RECORD_TYPE | Indicates the record format of a file. The value FIXED_LENGTH is for FITS data products. The physical record length (RECORD_BYTES) corresponds directly to the logical record length of the data objects (that is, one physical record for each image line, or one physical record for each row of a table). |
| RECORD_BYTES | Indicates the number of bytes in a physical file record, including record terminators and separators. For FITS data products, the value is 2880. |
| FILE_RECORDS | Indicates the number of physical file records, including both label records and data records. Note: In the PDS, the use of the file_records keyword along with other file-related data elements is fully described in the PDS Standards Reference. |

| /** OBJECT POINTERS **/ | |
|---|---|
| ^HEADER | This object identifies and defines the attributes of the FITS header for the primary image array (see ^IMAGE below). The use of bytes within the header object refers to the number of bytes for the entire header, not a single record, |
| ^IMAGE | This object defines the primary, two-dimensional FITS image array of sample values. Images are composed of LINES and SAMPLES. |
| ^EXT_FLAGS_QUALITY_HEADER | This object identifies and defines the attributes of the header for the quality map, an image extension in all raw and reduced FITS files. |
| ^EXT_FLAGS_QUALITY_IMAGE | This object provides the quality map, an image extension in all raw and reduced FITS files. The map or array is the same size as the primary image and provides information about the quality of each pixel in the primary image array. |
| ^EXT_WAVELENGTH_HEADER | Used only for calibrated, HRII images.<br>This object identifies and defines the attributes of the header for the pixel-by-pixel spectral wavelength map. |
| ^EXT_WAVELENGTH_IMAGE | Used only for calibrated HRII images.<br>This object provides the pixel-by-pixel spectral wavelength map. The array provides the wavelength for each pixel in the primary image array. |
| ^EXT_SPEC_BANDWIDTH_HEADER | Used only for calibrated HRII images.<br>This object identifies and defines the attributes of the pixel-by-pixel spectral bandwidth map. |
| ^EXT_ SPEC_BANDWIDTH _IMAGE | Used only for calibrated HRII images.<br>The object provides the pixel-by-pixel spectral bandwidth map. The array provides the spectral bandwidth for each pixel in the primary image array. |
| ^EXT_SNR_HEADER | Used only for calibrated images.<br>This object identifies and defines the attributes of the pixel-by-pixel, signal-to-noise ratio (SNR) map. |
| ^EXT_SNR_IMAGE | Used only for calibrated images.<br>The object provides the pixel-by-pixel SNR map. The array provides an signal-to-noise ration for each pixel in the primary image array. |

| /** DATA SET INFORMATION **/ | |
|---|---|
| DATA_SET_ID | Provides a unique alphanumeric identifier for a data set or a data product. The DATA_SET_ID is constructed according to instructions outlined in the PDS Standards Reference.<br>Source: Hardcoded. |
| MISSION_NAME | Provides the name of the mission: EPOXI.<br>Source: FITS header keyword MISSION. |
| INSTRUMENT_HOST_NAME | Provides the full name of the host on which an instrument is based. For EPOXI, there is only one value: Deep Impact Flyby Spacecraft.<br>Source: Derived from FITS header keyword OBSERVAT. |
| INSTRUMENT_HOST_ID | Provides a unique identifier for the host where an instrument is located. For EPOXI, there is only one value: DIF = DI flyby spacecraft.<br>Source: Derived from FITS header keyword OBSERVAT. |
| INSTRUMENT_NAME | Provides the full name of an instrument based on the value for INSTRUMENT_ID:<br>- Deep Impact High-Resolution Instrument - Infrared Spectrometer<br>- Deep Impact High-Resolutin Instrument - Visible CCD<br>- Deep Impact Medium-Resolution Instrument - Visible CCD<br>Source: FITS header keyword INSTRUME converted to one of the above values. |
| INSTRUMENT_ID | Provides an abbreviated name or acronym that identifies an instrument. The possible values are HRII, HRIV, and MRI.<br>Source: FITS header keyword INSTRUME converted from HRIIR, HRIVIS, MRIVIS to HRII, HRIV, or MRI, respectively. |

| /** PRODUCT INFORMATION **/ | |
|---|---|
| PRODUCT_ID | Represents a permanent, unique identifier assigned to a data product by its producer. Note: In the PDS, the value assigned to PRODUCT_ID must be unique within its data set.<br>Source: FITS file name with the period converted to an underscore. |
| PRODUCT_CREATION_TIME | Defines the UTC system format time when a product label was created. Formation rule: YYYY-MM-DDThh:mm:ss.<br>Source: FITS header keyword DATE. |
| PRODUCT_TYPE | Provides the type or category of a product within a data set. The possible values are:<br>RAW = Raw data record<br>RADIANCE_REVERSIBLE = Reversibly calibrated radiance data record<br>RADIANCE_CLEANED = Irreversibly cleaned, calibrated radiance data record<br>IOF_REVERSIBLE = Reversibly calibrated reflectance data record<br>IOF_CLEANED = Irreversibly cleaned, calibrated reflectance data record<br>Source: Hardcode based on the level of data reduction. |

| /** TIME INFORMATION **/ | |
|---|---|
| START_TIME | Provides the date and time, at the spacecraft, for the beginning of an observation in UTC system format. Formation rule: YYYY-MM-DDThh:mm:ss.fff. Source: FITS header keyword OBSDATE. |
| EPOXI:<br>IMAGE_MID_TIME | Provides the UTC date and time, at the spacecraft, of the midpoint between the start and end times. Formation rule: YYYY-MM-DDThh:mm:ss.fff. Source: FITS header keyword OBSMIDDT. |
| STOP_TIME | Provides the date and time, at the spacecraft, for the end of an observation in UTC system format. Formation rule: Formation rule: YYYY-MM-DDThh:mm:ss.fff. Source: FITS header keyword OBSENDDT. |
| START_JULIAN_DATE_VALUE | Provides the full Julian date corresponding to the UTC START_TIME of an exposure. Formation rule: nnnnnnn.nnnnnnn Source: FITS header keyword OBSJD. |
| MID_JULIAN_DATE_VALUE | Provides the full Julian date corresponding to the UTC IMAGE_MID_TIME of an exposure. Formation rule: nnnnnnn.nnnnnnn Source: FITS header keyword OBSMIDJD. |
| STOP_JULIAN_DATE_VALUE | Provides the full Julian date corresponding to the UTC STOP_TIME of an exposure. Formation rule: nnnnnnn.nnnnnnn Source: FITS header keyword OBENDJD. |
| SPACECRAFT_CLOCK_START_COUNT | Provides the value of the spacecraft clock at the beginning of an observation. Formulation rule: p/ssssssssss.fff where p is clock partition (1 for cruise and encounter phases), ssssssssss is the clock seconds count, fff is the sub-seconds tick (1 tick is 1/125$^{th}$ of a second). Source: FITS header keyword SCSTART. |
| EPOXI:<br>SPACECRAFT_CLOCK_MID_COUNT | Provides the value of the spacecraft clock at the midpoint of an observation. Formulation rule: p/ssssssssss.fff where p is clock partition (1 for cruise and encounter phases), ssssssssss is the clock seconds count, fff is the sub-seconds tick (1 tick is 1/125$^{th}$ of a second). Source: FITS header keyword ADCTIME. |
| SPACECRAFT_CLOCK_STOP_COUNT | Provides the value of the spacecraft clock at the end of an observation. Formulation rule: p/ssssssssss.fff where p is clock partition (1 for cruise and encounter phases), ssssssssss is the clock seconds count, fff is the sub-seconds tick (1 tick is 1/125$^{th}$ of a second). Source: FITS header keyword SCSTOP. |
| EPOXI:EARTH_OBSERVER_MID_TIME | Provides the mid-point of an observation for an observer on Earth in UTC system format. The difference between this time and the event time at the spacecraft is the light travel time from the spacecraft to earth. Formation rule: YYYY-MM-DDThh:mm:ss[.fff]. Source: FITS header keyword EAROBSDT. |

| /** OBSERVATION INFORMATION **/ | |
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| MISSION_PHASE_NAME | Identifies the mission phase:<br>CRUISE 1<br>EPOCH<br>CRUISE 2<br>DIXI<br>Source: Hardcode. |
| EPOXI:<br>MISSION_ACTIVITY_TYPE | Describes the type of mission activity such as “CRUISE CALIBRATION” or “LOOKBACK IMAGING”.<br>Source: FITS header keyword KPKIMNTL. |
| EPOXI:OBSERVATION_DESC | Identifies the purpose or type of the observation such as “Continuous comet imaging” or “Radiometry”.<br>Source: Concatenation of FITS header keywords KPKPCMMT and KPKICMMT. |
| TARGET_NAME | Identifies the intended mission target, such as “CALIBRATION”, “GJ 436”, or “103P/HARTLEY 2 (1986 E2)”. For raw data, TARGET_DESC provides the name of a “CALIBRATION” target.<br>Source: Derived from FITS header keyword OBJECT. |
| TARGET_DESC | Used only for raw data, provides the name of a calibration target, such as “CANOPUS” or “DARK”. For mission targets, this keyword is set to the value of TARGET_NAME. This keyword allows the user to more easily search for raw calibration data.<br>Source: FITS header keyword OBJECT. |
| INSTRUMENT_MODE_ID | Provides an instrument-dependent designation of operating mode. For the HRII instrument, valid modes are 1-7. For the HRIV and MRI instruments, the valid modes are 1-9.<br>Source: FITS header keyword IMGH030. |
| EPOXI:INSTRUMENT_MODE_NAME | Provides the common name used by the mission for INSTRUMENT_MODE_ID.<br>Source: FITS header keyword IMGMODEN. |
| EPOXI:<br>COMPRESSED_IMAGE_VALUE | Identifies a compressed or decompressed image:<br>UNCOMPRESSED = Image is not compressed<br>COMPRESSED = Raw image is compressed as received from the spacecraft<br>DECOMPRESSED = Reduced image is decompressed; all raw, compressed images are decompressed at the beginning of the calibration pipeline<br>Source: FITS header keyword COMPRESS. |
| COMPRESSOR_ID | Identifies the look-up table (compressor number) used to compress an image onboard the spacecraft and to decompress an image the calibration. Valid values are 0-3. Images that were never compressed in-flight this keyword set to “N/A”.<br>Source: If the file is compressed (if FNCMPRSS = “C” in FITS header), then set to FITS header keyword IMGH0001. |

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| EPOXI:OBSERVATION_ID | Identifies a set of images, also known as a sequence, taken by the same command using a 7-digit value. Also known as exposure ID. It is used with IMAGE_NUMBER. For example, exposure ID 9000000 and images number 2 identifies the second image taken for the commanded exposure ID.<br>Source: FITS header keyword EXPID. |
| IMAGE_NUMBER | An 3-digit value that identifies the order of an image within an exposure ID (see OBSERVATION_ID). Values are 001 through 999. One HRII OBSERVATION_ID typically consists of several, thus IMAGE_NUMBER is incremented for each frame in the sequence.<br>Source: FITS header keyword IMGH026. |
| EPOXI:<br>COMMANDED_IMAGE_COUNT | Provides to total number of images commanded for a specific observation (exposure) ID. See OBSERVATION_ID and IMAGE_NUMBER.<br>Source: FITS header keyword IMGH027. |
| FILTER_NUMBER | Provides the number, an integer, of the filter used for this observation. The Hall Sensor location was used because it was the best indicator of the actual filter used. A value of UNK indicates the filter could not be determined (is unknown). The HRII instrument did not have filter wheels, so this keyword is set to N/A (not applicable).<br><br>HRIV<br><pre>                    Center λ   Width<br> #  Name             (nm)       (nm)<br> --  --------------- ----------  ------------------------------<br> 1   CLEAR1      650        >700<br> 2   BLUE        450         100<br> 3   GREEN       550         100<br> 4   VIOLET      350         100 (cut-on is ~340 nm)<br> 5   IR          950         100 (longpass)<br> 6   CLEAR6      650        >700<br> 7   RED         750         100<br> 8   NIR         850         100<br> 9   ORANGE      950         100</pre><br>MRI<br><pre>                          Center λ   Width<br> #  Name                   (nm)       (nm)<br> --  ---------------------- -----------  -------------------------<br> 1   CLEAR1            650        >700<br> 2   C2                514        11.8<br> 3   GREEN_CONT        526         5.6<br> 4   RED               750        100<br> 5   IR                950        100 (longpass)<br> 6   CLEAR6            650        >700<br> 7   CN                387         6.2<br> 8   VIOLET_CONT       345         6.8<br> 9   OH                309         6.2</pre><br>Source: Decode FITS header keyword FILTER. |

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| FILTER_NAME | Provides the name of the filter used for this observation. The Hall Sensor location was used because it was the best indicator of the actual filter used. A value of "UNK" indicates the filter could not be determined. This keyword is not applicable for HRII and is set to "N/A".<br>Source: FITS header keyword FILTER. |
| CENTER_FILTER_WAVELENGTH | Provides the wavelength for the center of a filter bandpass in microns. A value of "UNK" indicates the filter could not be determined. This keyword is not applicable for HRII and is set to "N/A".<br>Source: FITS header keyword FILTERCW. |
| EPOXI:<br>INTEGRATION_DURATION | Provides the total integration time for the image in units of milliseconds. Integration duration is calculated as follows:<br>For HRII, all modes:<br>integration_duration = minimum_exposure_duration + commanded_exposure_duration<br>For HRIV and MRI shuttered modes (1, 2, 3, 5, and 9):<br>integration_duration = minimum_exposure_duration + commanded_exposure_duration<br>For HRIV and MRI unshuttered modes (4, 6, 7, and 8):<br>integration_duration = minimum_exposure_duration + commanded_exposure_duration + interframe_delay_duration + (0.5 ms if interframe_delay_duration > 0)<br><br>Source: FITS header keyword INTTIME. |
| EPOXI:SPACECRAFT_PROCESSOR_ID | Identifies one of two processor units onboard the DI spacecraft the processed and stored the image file.<br>Source: FITS header keyword SCUPROCU. |
| INSTRUMENT_TEMPERATURE | Provides the temperature, in degrees Kelvin, of an instrument or some part of an instrument. Multiple temperatures at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each temperature measurement in the INSTRUMENT_TEMPERATURE list with a corresponding item in the INSTRUMENT_TEMPERATURE_POINT sequence of values.<br><br>The temperature values were extracted from the original image headers that were generated onboard the spacecraft. Values from the nearest thermal telemetry were put in the image headers. For HRII, the best temperatures are in the thermal telemetry data set for the flyby spacecraft, DIF-C-HRII/HRIV/MRI-2/3-INST-TEMPS-V1.0<br><br>A value of "N/A" means the measurement was not applicable. A value of "UNK" indicated the measurement could not be determined or did not exist.<br><br>Source: FITS header keywords ICT590T, CCD590T, IR590T, LVPS590T, CCDPRET, CCDT, OPTBENT, PRIMIRT, SECMIRT, COVERT, and IRFPAT. |

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| INSTRUMENT_TEMPERATURE_POINT | Identifies the measurement point or location on an instrument or some part of an instrument. This keyword may be used in conjunction with INSTRUMENT_TEMPERATURE to more fully describe either single or multiple temperatures at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each temperature measurement in the INSTRUMENT_TEMPERATURE list with a corresponding item in the INSTRUMENT_TEMPERATURE_POINT sequence of values.<br><br>Values used for HRII and HRIV are:<br>INSTRUMENT CONTROLLER PROCESSING BOARD<br>CCD SIGNAL PROCESSING BOARD<br>IR SIGNAL PROCESSING BOARD<br>LVPS SIGNAL PROCESSING BOARD<br>CCD PREAMP BOX<br>CCD ON-CHIP SENSOR<br>PRISMS<br>PRIMARY MIRROR<br>SECONDARY MIRROR<br>SPECTRAL IMAGING MODULE COVER<br>IR FPA ON-CHIP SENSOR<br><br>Values used for MRI are:<br>INSTRUMENT CONTROLLER PROCESSING BOARD<br>CCD SIGNAL PROCESSING BOARD<br>IR SIGNAL PROCESSING BOARD<br>LVPS SIGNAL PROCESSING BOARD<br>CCD PREAMP BOX<br>CCD ON-CHIP SENSOR<br>OPTICAL BENCH<br>PRIMARY MIRROR<br>SECONDARY MIRROR<br>STRUCTURE COVER<br>IR FPA ON-CHIP SENSOR<br><br>Source: Hardcoded. |

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| INSTRUMENT_VOLTAGE | Provides the voltage, in volts, of an instrument or some part of an instrument. This keyword may be used in conjunction with INSTRUMENT_VOLTAGE_POINT to more fully describe either single or multiple voltages at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each voltage measurement in the INSTRUMENT_VOLTAGE list with a corresponding item in the INSTRUMENT_VOLTAGE_POINT sequence of values.<br><br>A value of "N/A" means the measurement was not applicable. A value of "UNK" indicated the measurement could not be determined or did not exist.<br><br>Source: FITS header keywords CCDOFSAV, CCDOFSBV, CCDOFSCV, CCDOFSDV, CCDOUTAV, CCDOUTBV, CCDOUTCV, CCDOUTDC, CCDSERPV, CCDSERNV, CCDPARPV, CCDPARNV, IRRESETV, IRSUBSTV, IRBIASGV, and ALLAMPV. |
| INSTRUMENT_VOLTAGE_POINT | Identifies the measurement point or location on an instrument or some part of an instrument. This keyword may be used in conjunction with INSTRUMENT_VOLTAGE to more fully describe either single or multiple temperatures at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each temperature measurement in the INSTRUMENT_VOLTAGE list with a corresponding item in the INSTRUMENT_VOLTAGE_POINT sequence of values.<br><br>The following values are used for all instruments:<br>CCD OFFSET FROM ADC REF QUAD A<br>CCD OFFSET FROM ADC REF QUAD B<br>CCD OFFSET FROM ADC REF QUAD C<br>CCD OFFSET FROM ADC REF QUAD D<br>CCD OUTPUT AMP DRAIN QUAD A<br>CCD OUTPUT AMP DRAIN QUAD B<br>CCD OUTPUT AMP DRAIN QUAD C<br>CCD OUTPUT AMP DRAIN QUAD D<br>CCD SERIAL CLOCK POSITIVE<br>CCD SERIAL CLOCK NEGATIVE<br>CCD PARALLEL CLOCK POSITIVE<br>CCD PARALELL CLOCK NEGATIVE<br>IR RESET<br>IR SUBSTRATE<br>IR BIASGATE<br>IR CALIB LAMP<br><br>Source: Hardcoded. |

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| /** IMAGE INFORMATION***/ | |
| HORIZONTAL_PIXEL_SCALE | Indicates the horizontal picture scale, in units of meters per pixel, for encounter phase data from the HRIV and MRI instruments. This keyword is set to “N/A” for HRII images. For non-planetary, calibration targets, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”.<br>Source: FITS header keyword PXLSCALE. |
| VERTICAL_PIXEL_SCALE | Indicates the vertical picture scale, in units of meters per pixel, for encounter phase data from the HRIV and MRI instruments. This keyword is set to “N/A” for HRII images. For non-planetary, calibration targets, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”.<br>Source: FITS header keyword PXLSCALE. |
| /** GEOMETRY PARAMETERS **/ | |
| NOTE | States that the Earth Mean Equator and Vernal Equinox J2000 (EME J2000) is the inertial reference frame, unless otherwise specified. Geometric parameters are based on the best available SPICE data at the time a product was produced. The observation midpoint was used to derive the geometry, and all positions are relative to body centers.<br>Source: Hardcoded. |
| EPOXI:GEOMETRY_QUALITY_FLAG | Indicates the quality of the geometry values. ‘OK’ indicates geometry is good. ‘BAD’ indicates the data should be used with caution.<br>Source: FITS header keyword GEOMSTAT.. |
| EPOXI:GEOMETRY_TYPE | Indicates if preliminary (‘PREDICTED’) or finalized (‘RECONSTRUCTED’) SPICE kernels were used to generate geometry values.<br>Source: FITS header keyword GEOMQUAL. |
| SPICE_FILE_NAME | Provides a list of the SPICE kernels used to calculate the values for the geometry-related. The kernels are listed in the order they were loaded for processing.<br>Source: FITS header keywords RECK0001 through RECK00nn if GEOMETRY_TYPE is ‘RECONSTRUCTED’ or NOMK0001 through NOMK00nn if GEOMETRY_TYPE is ‘PREDICTED’. |
| RIGHT_ASCENSION | Provides the right ascension, in the EME J2000 reference, where the boresight was pointing, in degrees.<br>Source: FITS header keyword BORERA for mission targets or UNK for calibration targets, |
| DECLINATION | Provides the declination, in the EME J2000 reference, where the boresight was pointing, in degrees.<br>Source: FITS header keyword BOREDEC for mission targets or UNK for calibration targets. |

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| CELESTIAL_NORTH_CLOCK_ANGLE | Specifies the direction of celestial north at the center of an image in the EME J2000 reference frame. It is measured in degrees from the 'upward' direction, clockwise to the direction toward celestial north when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements.<br>Source: FITS header keyword CELESTN for mission targets or UNK for calibration targets. |
| EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE | Specifies the direction of ecliptic north at the center of an image in the EME J2000 reference frame. It is measured in degrees from the 'upward' direction, clockwise to the direction toward ecliptic north when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements.<br>Source: FITS header keyword ECLN for mission targets or UNK for calibration targets. |
| EPOXI:SUN_DIRECTION_CLOCK_ANGLE | Specifies the direction to the Sun at the center of an image in the EME J2000 reference frame. It is measured in degrees from the 'upward' direction, clockwise to the direction toward the Sun when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements.<br>Source: FITS header keyword SOLARCLK for mission targets or UNK for calibration targets. |
| EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE | Specifies the direction of the IAU positive pole of the target body at the center of an image in the EME J2000 reference frame. It is measured in degrees from the 'upward' direction, clockwise to the positive pole when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements.<br>Source: FITS header keyword RECPPAZ or NOMPPAZ comet Hartley 2 frames only, otherwise use UNK. |
| SOLAR_ELONGATION | Provides the angle, in degrees, between the target, the Sun, and the observer at the mid-point of an observation.<br>Source: FITS header keyword SOLARELO for mission targets or UNK for calibration targets. |
| PHASE_ANGLE | Provides the angle, in degrees, between the Sun, the target, and the observer at the mid-point of an observation.<br>Source: FITS header keyword PHANGLE for mission targets or UNK for calibration targets. |
| TARGET_CENTER_DISTANCE | Provides the distance between the spacecraft and the center of the target, in units of kilometers. For targets outside the solar systsem, this keyword is set to "N/A". If geometry was not available, the components are set to "UNK".<br>Source: FITS header keyword TARSCR. |
| TARGET_HELIOCENTRIC_DISTANCE | Provides the distance between the target and the Earth, in units of kilometers. For targets outside the solar system, this keyword is set to "N/A". If geometry was not available, the components are set to "UNK".<br>Source: FITS header keyword TARSUNR. |

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| TARGET_GEOCENTRIC_DISTANCE | Provides the distance between the target and the Sun, in units of kilometers. For targets outside the solar system, this keyword is set to “N/A”. If geometry was not available, the components are set to “UNK”.<br>Source: FITS header keyword EARTARR. |
| EPOXI:SC_HELIOCENTRIC_DISTANCE | Provides the distance between the spacecraft and the Sun, in units of kilometers.<br>Source: FITS header keyword SCSUNR. For solar system targets, if SCSUNR is > 1.0E9 then this keyword is set to “UNK”. For targets outside the solar system, “N/A” is used. If geometry is bad, then “UNK” is used. |
| EPOXI:SC_GEOCENTRIC_DISTANCE | Provides the distance between the spacecraft and the Earth, in units of kilometers.<br>For targets outside the solar system, this keyword is set to “N/A”. If geometry was not available, the components are set to “UNK”.<br>Source: FITS header keyword SCEARR. |
| QUATERNION_DESC | Provides a pointer to an accompanying quaternion description file used to describe the formation rules for the quaternion and the specific rotation accomplished by application of that quaternion. This keyword is required to be used in conjunction with the QUATERNION keyword. The file to which this keyword points is to be included in the /document subdirectory of an archive product.<br>Source: Hardcoded to ‘QUATERNION_DESC.ASC’. |
| QUATERNION | Provides four-component representation of a rotation matrix. This quaternion rotates vectors defined in the instrument frame into the EME J2000 reference frame.<br>Source: FITS header keywords ADCQA, ADCQB, ADCQC, and ADCQD. If geometry could not be calculated, then use UNK. |
| EPOXI:<br>SC_ROTATION_VELOCITY_VECTOR | Provides the x-, y-, z-components of the angular velocity of the spacecraft about axes of the EME J2000 reference frame.<br>Source: FITS header keywords ADCVX, ADCVY, and ADCVZ. If geometry could not be calculated then UNK. |
| EPOXI:<br>TARGET_SC_POSITION_VECTOR | Provides the (x, y, z) components of the position vector, at image mid-time, from the target to the spacecraft expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”.<br>Source: FITS header keywords TARSCRX, TARSCRY, and TARSCRZ. |

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| EPOXI: TARGET_SC_VELOCITY_VECTOR | Provides the (x, y, z) components of the velocity vector, at image mid-time, from the target to the spacecraft expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers/second. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords TARSCVX, TARSCVY, and TARSCVZ. |
| TARGET_SUN_POSITION_VECTOR | Provides the (x, y, z) components of the position vector, at image mid-time, from the target to the Sun expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords TARSUNRX, TARSUNRY, and TARSUNRZ. |
| TARGET_SUN_VELOCITY_VECTOR | Provides the (x, y, z) components of the velocity vector, at image mid-time, from the target to the Sun expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers/second. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords TARSUNVX, TARSUNVY, and TARSUNVZ. |
| EARTH_ TARGET_POSITION_VECTOR | Provides the (x, y, z) components of the position vector, at image mid-time, from the target to the Earth expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords EARTARRX, EARTARRY, and EARTARRZ. |
| EARTH_ TARGET_VELOCITY_VECTOR | Provides the (x, y, z) components of the velocity vector, at image mid-time, from the target to the Earth expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers/second. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords EARTARVX, EARTARVY, and EARTARVZ. |

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| SC_SUN_POSITION_VECTOR | Defines the (x, y, z) components of the position vector, at image mid-time, from the spacecraft to the Sun expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers.<br>Source: FITS header keyword SCSUNRX, SCSUNRY, and SCSUNRZ. If SCSUNR is > 1.0E9 or the geometry is bad, then the compents of this vector are set to "UNK". |
| SC_EARTH_POSITION_VECTOR | Defines the (x, y, z) components of the position vector, at image mid-time, from the spacecraft to the Earth expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers.<br>Source: FITS header keywords SCEARRX, SCEARRY, and SCEARRZ. If the geometry if bad then the compenents of this vector are set to "UNK". |
| SUB_SPACECRAFT_LONGITUDE | Provides the longitude of the subspacecrat point, the point on a body that lies directly beneath the spacecraft. For targets outside the solar system, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK".<br>Source: FITS header keywords RECSCLON or NOMSCLON. |
| SUB_SPACECRAFT_LATTITUDE | Provides the latitude of the subspacecrat point, the point on a body that lies directly beneath the spacecraft. For targets outside the solar system, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK".<br>Source: FITS header keywords RECSCLAT or NOMSCLAT. |
| SUB_SOLAR_LONGITUDE | Provides the longitude of the subsolar point, the point on a body's reference surface where a line from the body center to the sun center intersects that surface. This keyword is used in conjunction with coordinate_system_type. For targets outside the solar system, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK".<br>Source: FITS header keywords RECSOLON or NOMSOLON. |
| SUB_SOLAR_LATTITUDE | Provides the lattitude of the subsolar point, the point on a body's reference surface where a line from the body center to the sun center intersects that surface. This keyword is used in conjunction with coordinate_system_type. For targets outside the solar system, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK".<br>Source: FITS header keywords RECSOLAT or NOMSOLAT. |

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| COORDINATE_SYSTEM_TYPE | Specifies the type of coordinate system used for the sub_spacecraft_longitude/latitude and sub_solar_longitude/latitude.<br>Source: Hardcoded to "BODY-FIXED ROTATING" if sub_spacecraft* and sub_solar* keywords are set to numeric values. |
| COORDINATE_SYSTEM_NAME | Provides the full name of the coordinate system associated with coordiate_system_type, sub_spacecraft_longitude/latitude, and sub_solar_longitude/latitude keywords.<br>Source: Hardcoded to "PLANETOCENTRIC" if sub_spacecraft* and sub_solar* keywords are set to numeric values. |

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| **/** PROCESSING HISTORY **/** | |
| EPOXI:SDC_PIPELINE_FILE_NAME | Provides the actual filename used in the data pipeline for this data file. The EPOXI project elected to modify and shorten the filename for the PDS archive. |
| PROCESSING_HISTORY_TEXT | For a reduced data file, lists the steps performed by the calibration process. Includes the names of the calibration files, such at the dark frame, used to reduce a data file. For raw, uncalibrated data, this keyword is set to RAW.<br>Source: Hardcoded. |
| **/** IMAGE STATISTICS **/** | |
| EPOXI:<br>BAD_PIXEL_COUNT | Provides a count of the number of known bad pixels in the image array, as identified by the calibration pipeline.<br>Source: FITS header keyword BADPXCT. |
| EPOXI:<br>MISSING_PIXEL_COUNT | Provides a count of the number of pixels that were not received from the spacecraft.<br>Source: FITS header keyword MISSPXCT. |
| EPOXI:<br>DESPIKED_PIXEL_COUNT | Provides a count of the number of pixels that were modified by the despiking routine in the calibration pipeline.<br>Source: FITS header keyword DESPIKCT. |
| EPOXI:<br>INTERPOLATED_PIXEL_COUNT | Provides a count of the number of pixels that were reclaimed, in the calibration pipeline, by interpolating from the values of neighboring good pixels.<br>Source: FITS header keyword INTERPCZT. |
| EPOXI:<br>PARTIAL_SATURATED_PIXEL_COUNT | Provides a count of the number of pixels where the raw value is above the point where some pixels have reached full-well saturation. For HRIV and MRI, this occurs at 11,000 DN. For HRII, this occur at 8,000 DN.<br>Source: FITS header keyword PSATPXCT. |
| EPOXI:<br>SATURATED_PIXEL_COUNT | Provides a count of the number of pixels where the raw value is above the point where most pixels have reached full-well saturation. For HRIV and MRI, this occurs at 15,000 DN. For HRII, this occurs at 11,000 DN.<br>Source: FITS header keyword SATPXCT. |
| EPOXI:<br>ADC_SATURATED_PIXEL_COUNT | Provides a count of the number of pixels where the analog-to-digital converter (ADC) was saturated.<br>Source: FITS header keyword ASATPXXCT. |
| EPOXI:<br>ULTRA_COMPRESSED_PIXEL_COUNT | Provides a count of the number of pixels where the raw DN is in a compression bin so large that the resulting value contains very little information.<br>Source: FITS header keyword ULTCMPCT. |

| /** OBJECT-RELATED KEYWORDS **/ | |
|---|---|
| BYTES | Indicates the number of bytes allocated for a particular data representation.<br>Source: Hardcoded to 2880. |
| HEADER_TYPE | Identifies a specific type of header data structure. For example: FITS. Note: In the PDS, HEADER_TYPE is used to indicate non-PDS headers.<br>Source: Hardcoded to FIXED. |
| INTERCHANGE_FORMAT | Represents the manner in which data items are stored. Example values: BINARY, ASCII.<br>Source: Hardcoded to BINARY. |
| RECORDS | Identifies the number of physical records in a file or other data object.<br>Source: Derived from the size of the FITS primary or extension image. |
| DESCRIPTION | Provides a free-form, unlimited-length character string that represents or gives an account of something.<br>Source: Hardcoded. |
| LINE_SAMPLES | Indicates the total integer number of data instances along the horizontal axis of an image.<br>Source: FITS header keyword NAXIS1. |
| LINES | Indicates the total integer number of data instances along the vertical axis of an image.<br>Source: FITS header keyword NAXIS2. |
| SAMPLE_BITS | Indicates the stored number of bits, or units of binary information, contained in a line sample value. The source is the FITS keyword BITPIX.<br>Source: Derived from FITS header keyword BITPIX. |
| SAMPLE_TYPE | Indicates the data storage representation of sample value such MSB_INTEGER, MSN_UNSIGNED_INTEGER, or IEEE_REAL.<br>Source: Derived from FITS header keyword BITPIX. |

| | |
|---|---|
| AXIS_ORDER_TYPE | Identifies the storage order for elements of a multidimensional ARRAY object. The default storage order for an ARRAY object presumes the rightmost or last index of a sequence varies the fastest. This is the ordering used in the C programming language and is equivalent to ROW_MAJOR storage order for COLUMN elements within tables.<br>Source: Hardcoded to FIRST_INDEX_FASTEST. |
| LINE_DISPLAY_DIRECTION | Identifies the preferred orientation of lines within an image for viewing on a display device. See also SAMPLE_DISPLAY_DIRECTION.<br>Source: Hardcoded to "UP" meaning lines must be displayed and viewed the bottom to the top in the graphics window. |
| SAMPLE_DISPLAY_DIRECTION | Identifies the preferred orientation of samples within a line for viewing on a display device. See also LINE_DISPLAY_DIRECTION.<br>Source: Hardcoded to "RIGHT" meaning samples must be displayed and viewed from left to right in the graphics window. |
| UNIT | Provides the full name or standard abbreviation of a unit of measurement in which a value is expressed:<br>• DATA NUMBER = Data number for RAW FITS<br>• W/(m**2 sr um) = Radiance units of Watts per meter-squared per steradian per micron; this values applicable only for the RAD and RADREV reduction types<br>• IF = Incidence over flux units for IF reduction type, unitless<br>Source: FITS header keyword BUNIT. |

| | |
|---|---|
| EPOXI:DERIVED_MINIMUM | Provides the smallest value occurring in a given instance of the primary image array after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from the value.<br>Source: FITS header keyword DATAMIN. |
| EPOXI:DERIVED_MAXIMUM | Provides the largest value occurring in a given instance of the primary image array after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from the value.<br>Source: FITS header keyword DATAMAX. |
| EPOXI:DERIVED_MEDIAN | Provides the median value (middle) occurring in a given instance of the data object after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from the value." Source: FITS header keyword MEDPVAL. |
| EPOXI:DERIVED_STANDARD_DEVIATI ON | Provides the standard deviation occurring in a given instance of the data object after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are \excluded from the value Source: FITS header keyword STDPVAL. |

# 5 Using the Data Products

## 5.1 Index Files

As noted in section 3, index files serve as indices into the data products contained in a data set. The index files include all of the values found in the data labels that are relevant to science, such as INSTRUMENT_MODE_ID, EPOXI: INTEGRATION_DURATION, etc.

## 5.2 Related Deep Impact Data Sets

Several raw, calibration-related data sets in the Deep Impact archive at the PDS may be useful for further analyses of instrument performance and calibration.

| PDS Data Set ID | DI Mission Phase(s) | Data Set Description |
|---|---|---|
| DIF-CAL-HRII-2-GROUND-TV1-V1.0 | Ground Calibrations | Raw FITS data from thermal-vacuum test TV1: June-July 2002 |
| DIF-CAL-HRII/HRIV-2-GROUND-TV2-V1.0 | Ground Calibrations | Raw FITS data from thermal-vacuum test TV2: August-September 2002 |
| DIF-CAL-HRII/HRIV/MRI-2-GROUND-TV4-V1.0 | Ground Calibrations | Raw FITS data from thermal-vacuum test TV4: February-March 2003 |
| DI-CAL-HRII/HRIV/MRI/ITS-2-GRND-TV5-V1.0 | Ground Calibrations | Raw FITS data from thermal-vacuum test TV5: June-August 2004 |
| DIF-CAL-HRII-2-9P-CRUISE-V1.0 | Cruise | HRII raw in-flight calibration data from January-April 2005 |
| DIF-CAL-HRIV-2-9P-CRUISE-V1.0 | Cruise | HRIV raw in-flight calibration data from January-April 2005 |
| DIF-CAL-MRI-2-9P-CRUISE-V1.0 | Cruise | MRI raw in-flight calibration data from January-April 2005 |
| DIF-C-HRII-2-9P-ENCOUNTER-V1.0 | Encounter | Includes additional HRII raw in-flight calibration data from May-July 2005 |
| DIF-C-HRIV-2-9P-ENCOUNTER-V1.0 | Encounter | Includes additional HRIV raw in-flight calibration data from May-July 2005 |
| DIF-C-MRI-2-9P-ENCOUNTER-V1.0 | Encounter | Includes additional MRI raw in-flight calibration data from May-July 2005 |

## 5.3 Flight Hardware Considerations

Analysis of Deep Impact data indicated a 1- to 2-second discrepancy between the spacecraft clocks for the flyby, spacecraft, the impactor spacecraft, and UTC. A report of this discrepancy is included in the DOCUMENT directory because this effect may be relevant for EPOXI.

## 5.4 Known Anomalies

The EPOXI project acknowledges the calibration process for the HRII spectral image data is being improved. In particular, the effects of the beam splitter on the IR signal and methods for flat fielding are still being analyzed.

## 5.5 Recommended Software to Read Data Products

### 5.5.1 IDL

The EPOXI project used IDL to calibrate and analyze all flight data. The LINE_DISPLAY_DIRECTION and SAMPLE_DISPLAY_DIRECTION keywords in the product labels describe how the data should be displayed.

### 5.5.2 PDS-SBN Tools

The EPOXI project recommends an IDL-based tool, called READPDS, to display and analyze data products. This tool was developed by the PDS SBN and is available at the SBN website, http://pdssbn.astro.umd.edu. The purpose of this tool is to enable users to display and examine data products (i.e., a detached PDS labels and its data file) archived at the SBN.

# 6 Technical/Programming Information

## 6.1 Brief Description of ODL used for PDS Labels

ODL is an object description language used to describe the structure or contents of a file. The following is an example of an ODL label that describes a data file that contains an image:

```
FILE_TYPE = FIXED
OBJECT       = IMAGE
   LINES            = 1024
   LINE_SAMPLES        = 1024
   …
END_OBJECT     = IMAGE
  …
END
```

The ODL label describes each meaningful section of data. PDS labels use ODL conventions. For more information about ODL and PDS labels, refer the PDS Standards Reference [1].

## 6.2 Architecture Notes

### 6.2.1 Internal Representation of Data Types

The following internal representation of data types are used:

- IEEE_REAL, IEEE-format, floating-point numbers
- MSB_INTEGER, signed integers using Most Significant Byte first (MSB) order
- MSB_UNSIGNED_INTEGER, unsigned integers using Most Significant Byte first (MSB) order

For more information about these internal representations, refer the Appendix C of the PDS Standards Reference [1].

### 6.2.2 File System (ISO 9660)

The ISO 9660 Level 2 file system is used including these PDS conventions:

- There are no more than eight, nested directory levels
- File names are a maximum of 31 characters long, with no more than three characters in the suffix (i.e., 27.3).

## 6.3 File Compression

Some raw science images in the EPOXI archive are stored in a compressed format (8-bit unsigned integers). These data were compressed by software onboard the spacecraft using one of four, simple, instrument-specific lookup tables and received on the ground, processed by the data pipeline, and archived in the same format. Values in the compressed, raw FITS images vary from 0 to 255 DN. The first step in the calibration pipeline uncompresses these data using the appropriate decompression lookup table. These tables are provided as ASCII tables with detached PDS labels in CALIB/ directory of the raw and reduced science data sets. For more information, see Klaasen, et al. 2008 [7].

## 6.4 Accessing Quality Flags Map via IDL

This section explains how to use IDL to access the information in the pixel-by-pixel Quality Flag Map described in section 3.1.3.

Because each pixel in the quality map is a collection of 8 bits, one must think binary when interrogating the bits. For example if an image pixel is only flagged as bad by the quality flags map, then only the right-most bit (bit 0 or the least-significant bit) in the corresponding quality pixel will be turned on and its value will be 2^0 or 1. If the calibration pipeline determined the ***raw*** value of the pixel was above the limit where some pixels saturate and no other flag has been set, then the fifth bit from the right (bit 4) will be turned on and the value of the corresponding pixel in the quality flags map will be 2^4 or 16. For an example using an IR image pixel with a raw value of 12000 DN, a value of 49 (=1+16+32) in a quality pixel indicates three things:

1) The pixel is bad (2^0 = 1),
2) The raw pixel value is above the point (8000 DN for IR) where some pixels are full-well saturated (2^4 = 16), and
3) The raw pixel value is above the point (11000 DN for IR ) where most pixels are full-well saturated (2^5 = 32).

If a pixel is rather saturated, the calibration pipeline sets bits 4 and 5 because the pixel first failed the "some pixels saturated" test then it failed the "most pixels saturated" test. It is important to note that if this quality pixel was interrogated as an unsigned integer instead of by its individual bits, then any odd integer value indicates only a bad pixel.

Here is a sample of IDL code that can be used to interogate the 8-bit quality flag pixels. The code sets variables that can be used to check. If you print each variable, you will see the resulting ***bit*** values:

```
; Set variables for checking individial quality flags.
print,FLAG_BAD = ishft(1,0)             ; = 2^0 = 1
print,FLAG_GAP = ishft(1,1)             ; = 2^1 = 2
print,FLAG_SPIKE = ishft(1,2)           ; = 2^2 = 4
```

```
print,FLAG_INTERP = ishft(1,3)          ; = 2^3 = 8
print,FLAG_SOMEFULLWELL= ishft(1,4)     ; = 2^4 = 16
print,FLAG_MOSTFULLWELL = ishft(1,5)    ; = 2^5 = 32
print,FLAG_ADCSAT = ishft(1,6)          ; = 2^6 = 64
print,FLAG_ULTRACOMPRESS = ishft(1,7)   ; = 2^7 = 128
```

To check if a pixel is bad, use IDL's bitwise AND operator on the quality pixel (qualmap) and the FLAG_BAD variable and compare the result to 0 (the note at the end of the attached IDL program explains why the result must be compared to 0):

```
if (qualmap[25,18] and flag_bad) ne 0 then print,'Bit 0 is on; Bad pix'
```

To locate the good and bad pixels, use:

```
badpix  = where((qualmap and flag_bad) ne 0))
goodpix = where((qualmap and flag_bad) eq 0))
```

To locate pixels with raw values that were above the point where most IR pixels are full-well saturated (11000 raw DN), use:

```
mostsat = where((qualmap and flag_mostfullwell) ne 0))
```

In IDL, the AND is a bit-by-bit logical AND operation. It does all the bits. However, if the result is used in an IF statement or WHERE call in IDL, it will return FALSE because the least-significant bit of the result is 0. Therefore, the result must be compared to "NE 0" to produce the correct results for an IF or WHERE in IDL.

## 6.5 NAIF/SPICE

Geometry values found in the PDS data labels were generated from SPICE files, also known as kernels that were produced by NAIF for EPOXI. These kernels are archived as a separate data set.

The SPICE system used to compute geometry information is available at the http://naif.jpl.nasa.gov/naif/pds.html. The system is available in several programming languages (FORTRAN, C, and IDL) and for most computer platforms such as Sun Solaris and Mac. The SPICE software, mostly in the form of subroutines, allows users to read SPICE kernels and compute desired observation geometry such as lighting angles, distances, and latitudes or longitudes. Documentation for the SPICE system is available from the NAIF website.

# 7 Appendices

## *7.1 Glossary*

**Archive -** An archive consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.

**Archive Volume, Archive Volume Set** - A volume is a unit of media on which data products are stored; for example, one DVD. An *archive volume* is a physical volume containing all or part of an archive; that is, one or more data sets plus documentation and ancillary files. When an archive spans multiple volumes, they are called an *archive volume set*. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone.

**Catalog Information** - Descriptive information about a data set (e.g. mission description, spacecraft description, instrument description), expressed in Object Description Language (ODL) which is suitable for loading into a PDS catalog.

**Data Product** - A labeled grouping of data resulting from a scientific observation, usually stored in one file. A product label identifies, describes, and defines the structure of the data. An example of a data product is a planetary image, a spectrum table, or a time series table.

**Data Set -** An accumulation of data products. A data set together with supporting documentation and ancillary files is an archive.

**Standard Data Product** - A data product that has been defined during the proposal and selection process and that is contractually promised by the PI as part of the investigation. Standard data products are generated in a predefined way, using well-understood procedures, and processed in *pipeline* fashion. Data products that are generated in a nonstandard way are sometimes called *special data products*.

## 7.2 Acronyms

| | |
|---|---|
| ASCII | American Standard Code for Information Interchange |
| CODMAC | Committee on Data Management and Computing |
| NASA | National Aeronautics and Space Administration |
| DN | Data number |
| DI | Deep Impact |
| DIXI | Deep Impact eXtended Investigation |
| EME J2000 | Inertial reference frame for the Earth Mean Equator (EME) and Vernal Equinox J2000 |
| EPOCh | Extrasolar Planet Observation and Characterization investigation |
| EPOXI | EPOCh + DIXI |
| FITS | Flexible Image Transport System |
| HRI | High Resolution Instrument/Telescope |
| HRII | High Resolution Instrument, Infrared Spectrometer |
| HRIV | High Resolution Instrument, Visual CCD |
| IEEE | Institute of Electrical and Electronics Engineers |
| IF | Nomenclature for irreversibly cleaned, calibrated data (CODMAC level 4) in units of reflectance, also known as I-over-F or I/F, and defined as the radiance divided by the solar spectrum multiplied by pi; For DI, I/F data are unitless |
| IDL | Interactive Data Language, a data visualization and analysis platform |
| IR | Infrared |
| MRI | Medium Resolution Instrument, Visual CCD |
| ODL | Object Description Language |
| PDS | NASA Planetary Data System |
| PI | Principle Investigator |
| FITS | Flexible Image Transport System |
| NAIF | Navigation and Ancillary Information Facility |
| NASA | Navigation Aeronautics and Space Administration |
| RAW | Nomenclature for edited, raw data (CODMAC level 2) in units of DN |
| RAD | Nomenclature for irreversibly cleaned, calibrated data (CODMAC level 4) in units of radiance |
| RADREV | Nomenclature for reversibly calibrated data (CODMAC level 3) in units of radiance; data are not cleaned |
| SBN | Small Bodies Node of the PDS |
| SDC | Deep Impact Science Data Center at Cornell University |
| SIS | Software Interface Specifications |
| SPICE | Spacecraft, Planet, Instrument, Pointing C-matrix, and Event kernels (a historical acronym for NAIF) |
| TV | Thermal-vacuum Test (ground calibrations) |

## 7.3 Data Processing Levels

| CODMAC Level | Proc. Type | Data Processing Level Description |
|---|---|---|
| **1** | Raw Data | Telemetry with data embedded. |
| **2** | Edited Data | Corrected for telemetry errors and split or decommutated into a data set for a given instrument. Sometimes called Experimental Data Record (EDR). Data are also tagged with time and location of acquisition. Corresponds to NASA Level 0 data. |
| **3** | Calibrated Data | Edited data that are in units produced by instrument, but have been corrected so that values are expressed in or are proportional to some physical unit such as radiance. No resampling, so edited data can be reconstructed. Corresponds to NASA Level 1A. |
| **4** | Resampled data | Data that have been resampled in the time or space domains in such a way that the original edited data cannot be reconstructed. Could be calibrated in addition to being resampled. Corresponds to NASA Level 1B. |
| **5** | Derived Data | Derived results, as maps, reports, graphics, etc. Corresponds to NASA Levels 2 through 5 |
| **6** | Ancillary Data | Non-Science data needed to generate calibrated or resampled data sets. Consists of instrument gains, offsets; pointing information for scan platforms, etc. |
| **7** | Correlative Data | Other science data needed to interpret space-borne data sets. May include ground based data observations such as soil type or ocean buoy measurements of wind drift. |
| **8** | User Description | Description of why the data were required, any peculiarities associated with the data sets, and enough documentation to allow secondary user to extract information from the data. |
| **n** | n | Not Applicable |